THE
POPULAR SCIENCE
MONTHLY.

NOVEMBER, 1909

THE SHIFTING OF THE EARTH'S AXIS

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THE earth has two principal motions, one of revolution about the sun, the other of rotation upon an axis. The revolution about the sun is accomplished in 365¼ days at an average speed of nineteen miles per second, or thirty-three times the speed of the swiftest modern projectile. The rotation upon its axis is accomplished in twenty-four sidereal hours, and since the equatorial circumference of the earth is nearly 25,000 miles, a point on the earth's equator has a speed of rotation of over one thousand miles per hour.

In form the earth is an oblate spheroid, a flattened sphere, and the axis about which it rotates coincides very nearly with the shortest axis of the body. If a plane be passed through the center of the earth perpendicular to the *axis upon which it rotates,* not perpendicular to the shortest axis, this plane will cut the surface in a circle which is known as the equator. One of the two coordinates by which the location of a place on the earth's surface is designated is its distance north or south of the equator—measured in degrees, not in miles—and this coordinate is called latitude.

Let the small circle at the center of Fig. 1 represent a section of the earth through the plane of any meridian and the large circle the line in which this plane extended cuts the celestial sphere, supposedly at an infinite distance, $P'P''$ being the direction of the axis upon which the earth rotates and CE the line in which the plane of the equator cuts the given plane. Let O be the place of observation and NS the line in which a plane through the center of the earth parallel to the horizon plane at O cuts the plane of the meridian. According to the definition the arc EO is the latitude of the place O and it is easily seen from the figure that this arc is equal to the corresponding arc on the sky $E'Z$,

the declination of the zenith—declination being defined in a way exactly similar to latitude, *i. e.*, the angular distance of a point on the sky north or south of the celestial equator. Latitude is usually designated by the Greek letter ϕ and it may be seen from the figure that a third definition of latitude is the angular distance of the celestial pole above the horizon—the altitude of the celestial pole.

Many methods of determining latitude have been devised, some of them coming down to us from the ancient Chaldean and Egyptian astronomers. The simplest method is to measure the altitude of the sun at noon on the day it passes through the equinox. On that day, the sun will cross the meridian at the point E', and its altitude will then be $90° - \phi$, as may be readily seen from the figure. A rough value of

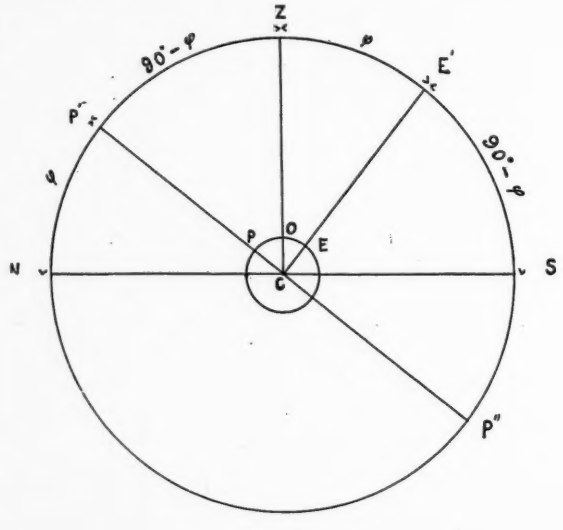


FIG. 1.

this angle may be obtained by measuring the shortest shadow of a vertical stick on a level piece of ground on the day of the equinox. The height of the stick divided by the length of the shortest shadow is the tangent of the complement of the latitude.

If the earth be considered a rigid body and the axis upon which it rotates *be fixed* within the body of the earth, the latitudes of all places upon its surface *will remain always the same.* If, however, the axis should shift its position within the earth, then the equatorial plane, which must be always perpendicular to the axis, must shift and consequently the latitudes of all places on the earth's surface must change accordingly.

It is well established that, at least during historic times, no changes of any considerable magnitude have occurred in the latitudes of places on the earth. It has long been suspected by astronomers, however, that

minute changes of latitude were taking place, but it is only during the last quarter century that the methods of observation and calculation have reached that degree of refinement necessary to detect these small changes.

In 1884 and 1885 Dr. Küstner, astronomer at the Royal Observatory of Berlin, made a series of observations upon certain stars for the purpose of determining the constant of aberration—the maximum apparent displacement of a star due to the finite ratio between the speed of the earth in its orbit and the velocity of light. One of the quantities used in the reduction of these observations is the latitude of the place of observation. Dr. Küstner found his results to be discordant, much more so than he had good reason to believe that they should be from the known care and precision with which the observations were made. Upon investigation it was found that these discrepancies could be almost entirely explained away by assuming a change in the latitude. Dr. Küstner, therefore, in 1888, made the bold announcement that the latitude of the Berlin Observatory had changed during the period over which his observations extended.

This announcement aroused wide-spread interest and steps were immediately taken by the International Geodetic Association[1] to test the reality of the announced variation. Through the cooperation of the observatories at Berlin, Potsdam, Prague and Strassburg, observations for latitude were begun in 1889 and carried on continuously for over a year. These observations agreed in showing a minute but appreciable change in the latitude. In order to test the matter still further, an expedition was sent in 1891–2 to Honolulu, and observations for latitude were made there simultaneously with others made at the observatories just named. As Honolulu is on the opposite side of the earth from Europe, it is seen at once, from Fig. 1, that if the latitude were increasing at the European observatories a corresponding decrease should be shown at the Honolulu station. The results came out as expected and this was generally accepted as a complete demonstration of the reality of this phenomenon. Fig. 2 gives a graphical representation of the results, time being measured along the horizontal and latitude along the vertical line.

The observations thus far made showed that the changes in latitude were periodic in character, that is, the latitude of any place would increase for a certain length of time and then decrease to a minimum value and so on, continuing to oscillate between certain limits. It is easily seen that such changes in the latitude of any place may be

[1] The International Geodetic Association has its headquarters at Potsdam, Germany, and is supported by the principal governments of Europe, the United States, the Argentine Republic and Japan. It carries out pieces of geodetic and astronomical work which are international in their scope.

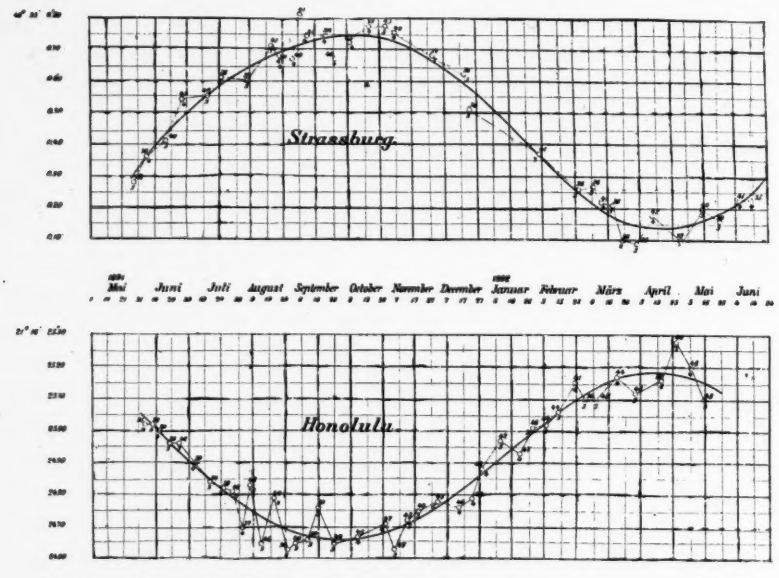

Strassburg.
Mai Juni Juli August September October November December 1900 Januar Februar März April Mai Juni
Honolulu.

FIG. 2. The upper figures denote the number of stars observed, the lower figures, the number of days on which observations were made.

explained through the assumption of a revolution of the axis of rotation about the shortest axis of the earth, or the axis of figure as it is called.[2] In Fig. 3 let PP_1 be the axis of figure and $P'P_1'$ the position of the axis of rotation at a time when P and P' lie in the meridian of the place of observation O, and let $E'E_1'$ be the line in which the plane of the equator cuts the meridian plane of this place. If now the axis of rotation is given a motion of revolution about the axis of figure, then when one half a revolution has been completed the axis of rotation will be in the position $P''P_1''$, the equator line will have shifted to $E''E_1''$, and the latitude of the place O will have changed from $E'O$ to $E''O$, the whole change in the latitude, $E'E''$ being $2i$, or twice the angle between the axis of figure and the axis of rotation. After a complete revolution of the axis has been accomplished the latitude of the place O will again be $E'O$ and it will oscillate between the maximum value $E'O$ and the minimum value $E''O$. The reader should bear in mind that the figure is grossly exaggerated, the actual value of the angle i being less than one half of a second of arc. If the angle i remains constant and the axis of rotation revolves about the axis of figure with a uniform speed then the place of observation will apparently swing back and forth in its meridian through an arc equal to $2i$. If the

[2] The usual statement of the problem is the converse of that just given, that is, that the axis of figure revolves about the axis of rotation, but the effect is the same, provided the distance from O to the end of the shortest axis remains constant, and for purposes of illustration the above statement of the problem seems simpler. The direction of the axis in space remains nearly fixed, but its position within the earth is not fixed.

values of the latitude be plotted along a vertical line and time along the horizontal, we shall obtain the representation of a simple harmonic motion, the crest of the wave corresponding to a maximum value of the latitude and the trough of the wave to the minimum value.

About the time of the expedition to Honolulu, Dr. Seth C. Chandler, of Cambridge, Mass., one of America's foremost astronomers, took up the subject of the variation of latitude and through a brilliant series of

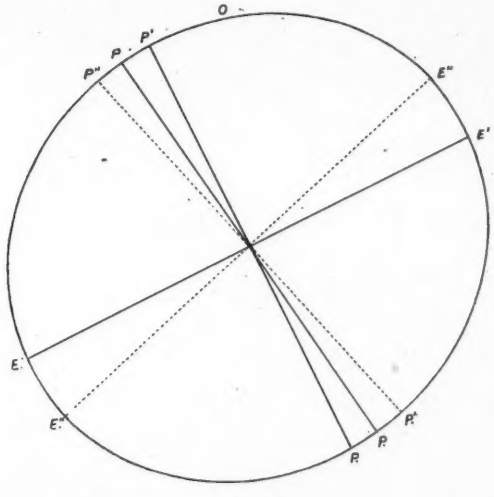


FIG. 3.

researches, published in the *Astronomical Journal,* succeeded in setting forth a number of very interesting results. Dr. Chandler examined all the astronomical observations made with transit instruments, meridian circles, zenith tubes and allied forms of instruments, which were at all suitable for throwing light upon the subject. The first and most interesting result obtained by Dr. Chandler was that the period of the latitude variation was about 427 days. He showed that the observations of the eighties and nineties could be represented very well by assuming that the axis of figure of the earth revolves about the axis of rotation in a circle of thirty feet radius in a period of 427 days.

Dr. Chandler's investigations of earlier observations, which run back as far as Bradley's classic observations for the determination of the constants of precession and nutation made with a zenith tube in the early part of the eighteenth century, seem to show that the period of variation was formerly considerably shorter than at present, the observations of the eighteenth century seeming to demand a period of about 370 days. Later observations showed also that the *amplitude* of the change is not constant, so that the change in latitude can not be accurately represented by assuming that one axis revolves about the other in a circle of thirty feet radius. Chandler's later conclusion is that

the motion of the earth's pole may be conveniently separated into two motions, one an annual revolution in a narrow ellipse about thirty feet long and eight feet wide, but varying in form and position, the other a revolution in a circle about twenty-six feet in diameter with a period of 427 days; both motions being counter clockwise. The resultant of these two motions is quite irregular, as may be seen by referring to Fig. 6, which will be explained later.

From Dr. Chandler's investigations and from the observations for latitude made during the early nineties, it became evident that the movement of the earth's pole was a very complicated one and that an accurate determination of its motion could be obtained only through continuous observations of the latitude at various places on the earth's surface. In 1896 a plan was promulgated by the International Geodetic Association whereby it was proposed to establish stations for the express purpose of observing the latitude. For reasons to be stated later these observatories were all to be located on the same parallel of latitude and in selecting them, social, hygienic, seismological and meteorological, as well as mathematical, conditions were considered, the prime requisite being, of course, that all of the stations have a fair proportion of clear nights at all seasons of the year. Seventeen different combinations of stations lying between latitudes $+ 36° 48'$ and $+ 44° 50'$, and including two combinations in the southern hemisphere on parallels $- 33° 54'$ and $- 33° 27'$, were considered. The parallel of $+ 39° 8'$ was finally chosen with the stations located in Japan, in Italy and the eastern and western parts of the United States. Two other stations were subsequently added, one in Central Asia and the other in the central part of North America, at Cincinnati.

The preliminary work of establishing the stations occupied about three years and observations were begun at all of them in the fall of 1899. The Japanese station is situated very close to the city of Mizusawa (10,000 inhabitants), which lies in a fertile valley 290 miles north of Tokio. The valley is nearly enclosed by two ranges of mountains, having a general northerly and southerly direction, the highest peak of which is 6,700 feet above sea-level. The meteorological conditions at this station are not especially favorable. There is a large range between summer and winter temperatures and the percentage of cloudiness is greater than at any other station. Nevertheless, the two observers, Dr. H. Kimura, director, and Dr. T. Nakano, observer, who have served continuously since the observatory was established, have obtained a most excellent series of results. The number of earthquakes at Mizusawa is large, but the locality is not affected by these disturbances as much as some other portions of Japan. Since the observatory was established there has been none of sufficient intensity to seriously affect the observations.

The Central Asian station is located in the Russian possessions east

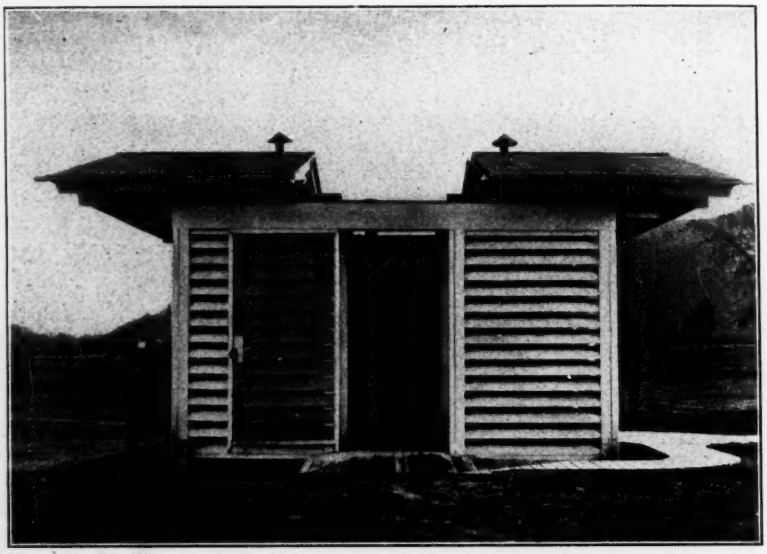
of the southern end of the Caspian Sea, six miles northwest of the city of Tschardjui and two miles from the left bank of the Amu Daria, or River Oxus. The observatory is located on an oasis in a sand-waste traversed by many canals. There is a greater range in the annual temperature at this station than at any of the others. Tschardjui is affected by very few earthquakes. The observations at this station are made by a single observer, several having taken part thus far, all of them officers of the Russian army.

The Italian station is very picturesquely located on an old tower, San Vittorio, close to the city of Carloforte, on the island of San Pietro, which lies west of the southern end of the island of Sardinia. The tower is located on a peninsula on the east side of the island, so that the meridian of the observatory lies almost entirely over the Mediterranean Sea, and anomalies in refraction would seem to be absolutely excluded. The island is free from mountains, the highest point being some 650 feet above sea-level. Carloforte has 8,000 inhabitants and can be reached from Cagliari, the chief city of Sardinia, in eight hours. The meteorological conditions at Carloforte are very favorable. The annual variation of temperature is less than at any other station and over 70 per cent. of the nights are clear, a condition which prevails, I believe, in no other section of the world than that surrounding the Mediterranean Sea. The island is free from earthquakes, there having been only four in nearly four hundred years of any considerable intensity, and none of these destructive. The observations at this station are made by two observers, who alternate with the nights. Several changes in the staff have taken place thus far, but all its members have been Italian astronomers.

The station in the eastern part of the United States is located half a mile south of the village of Gaithersburg, Maryland, twenty-one miles northwest of the city of Washington. The surrounding country is hilly, the observatory has an altitude of 540 feet above sea level and the meteorological conditions are fairly favorable. Mr. Edwin Smith, of the Coast and Geodetic Survey, made the observations at this station during the first year; Dr. Herman S. Davis during the succeeding five years. The work is now in charge of Dr. Frank E. Ross.

After the parallel of 39° 8′ had been selected for the location of the latitude observatories it was found that this parallel passed through the grounds of the Observatory of the University of Cincinnati, and Professor J. G. Porter, director of the observatory, volunteered to carry on observations if he were provided with an instrument. The observatory is located on a hill, five miles northeast of the city, and one mile east of the Ohio River. The altitude of the observatory is 800 feet above sea-level and the meteorological conditions are fairly favorable. Thus far all of the observations, except a few during the summer months, have been made by Professor Porter.

The sixth station is situated in California, 112 miles north of San Francisco, one mile south of the city of Ukiah, the county seat of Mendocino County. The observatory is located toward the western edge of one of the numerous small valleys in the Coast Range of mountains. The valley, which is traversed by the Russian River, is about ten miles long and from two to three miles wide, and surrounded by mountains of an average height of about 1,300 feet above the floor of the valley. The altitude of the observatory is 700 feet above sea-level. The meteorological conditions at this station are very favorable, standing next to those of Carloforte in this respect. Snow seldom falls and, although



INTERNATIONAL LATITUDE OBSERVATORY, UKIAH, CALIFORNIA. (Looking South.)

the summer temperatures are sometimes extreme, the nights are always cool, which adds much to the comfort of the observer if not to the accuracy of the observations. Up to May, 1903, the observations at this station were made by Dr. Frank Schlesinger, now director of the Allegheny Observatory; from that time until September, 1907, the observations were made by the writer of this article. The work is now in charge of Dr. James D. Maddrill.

From a seismological point of view, all the American stations are favorably located. Although the Pacific Coast of the Americas is well recognized as a region of seismic activity, yet the mountainous nature of the country surrounding Ukiah seems to afford a measure of protection from these disturbances. No earthquake since the observatory was established, not even the great shock of April 18, 1906, has been of sufficient intensity to interfere in any way with the progress of observations.

The four stations first established, Mizusawa, Carloforte, Gaithersburg and Ukiah, are provided with zenith telescopes of exactly the same pattern, and constructed especially for this work of observing latitudes by the Talcott method.[3]

These instruments, illustrated in Fig. 4, were made by Wanschaff, of Berlin, and have objectives of $4\frac{1}{4}$ inches aperture and focal lengths of fifty-one inches. The instruments at Tschardjui and Cincinnati are of similar design by the same maker, but smaller. From the figure it may be seen that the telescope is fixed perpendicular to the end of a horizontal axis. By placing this axis in an east and west direction the telescope will move only in the plane of the meridian as the horizontal axis is rotated in its supports. The whole instrument may be revolved about the vertical axis, *m*, and by properly adjusted stops on the base-piece the amount of rotation may be limited to 180°, thus giving two east and west positions for the horizontal axis, one, telescope east, the other, telescope west. It is readily seen that if the telescope is set to point say 10° north of the zenith when east of the vertical axis, then, without disturbing the setting of the telescope, if the whole instrument be revolved about the vertical axis, the telescope will, when it comes into the position west of the axis, be pointed 10° *south* of the zenith. It is thus possible to measure the *difference* of zenith distance of two stars,

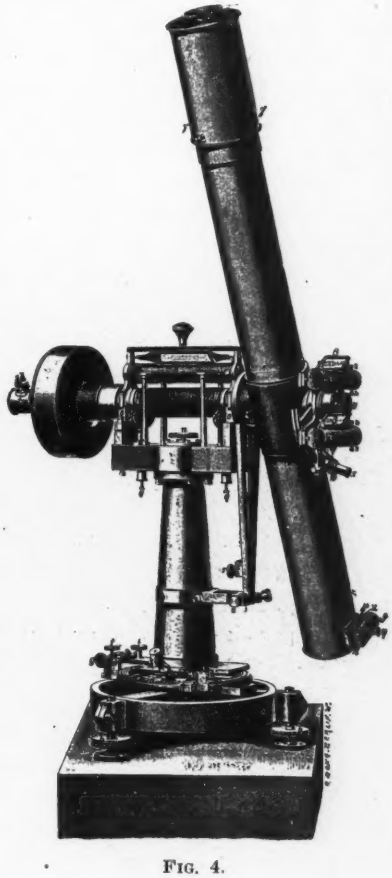


FIG. 4.

[3] Descriptions of this method may be found in any work on practical astronomy. The following statements concerning the method may be of help to those who are not familiar with its details. In order to make a determination of the latitude by this method it is necessary to measure, by means of an eye-piece micrometer attached to the zenith-telescope, the *difference* of zenith distance of two stars of known declination which culminate at nearly equal zenith-distances, one north of and the other south of the zenith. The telescope is set at the mean of the zenith-distances of the two stars and the first to culminate will pass a little above or below the middle of the field of view. The distance from the

one of which culminates on one side of the zenith and the other at nearly the same distance on the opposite side of the zenith, by means of an eye-piece micrometer rather than a graduated circle, and herein lies the chief advantage of the Talcott method over all others, the micrometer being a much more delicate and accurate instrument than the graduated circle.

The program of work calls for sixteen determinations of the latitude each night, which means the observation of sixteen pairs of stars. Particular stars have been chosen in such a way as to give convenient intervals between the culmination times of each and the work consumes four hours of time each night. As the stations are all located on the same parallel of latitude the zenith of each observatory will traverse the same path in the sky and the same stars may therefore be observed at each station. Exactly the same program of work, weather and other conditions permitting, is carried out at each station every night of the year. About 12,000 determinations of the latitude are obtained each year, the total to the beginning of 1908 being 99,313. The greatest number of observations are obtained at the Italian station, the next greatest at Ukiah, as may be seen from the following table:

TOTAL OF LATITUDE OBSERVATIONS UP TO 1908

Mizusawa	13,561	Cincinnati	12,190
Tschardjui	14,901	Ukiah	18,676
Carloforte	25,302	Total	99,313
Gaithersburg	14,683		

middle is measured by means of the micrometer. The instrument is then reversed about its vertical axis, without disturbing the setting, and the telescope will then point as far south as it did north of the zenith before reversal, or *vice versa*. The second star will then pass through the field of view as far below or above as the first star was above or below the center, and this distance from the center is again measured by means of the micrometer. The proper combination of the micrometer settings on the two stars gives the actual difference of their zenith-distances, which may be turned into arc measure, provided the value of one revolution of the micrometer-screw be known. The latitude, ϕ, of the place of observation is computed by means of the formula,

$$\phi = \tfrac{1}{2}(\delta_n + \delta_s) + \tfrac{1}{2}(m_n - m_s)R + \tfrac{1}{2}(l_n + l_s) + \tfrac{1}{2}(r_n - r_s),$$

in which the first term of the right-hand member of the equation represents one half the sum of the declinations of the two stars of the pair observed; the second term one half the difference of the zenith-distances of the two stars as measured by means of the micrometer; the third term a small correction for any change in the pointing of the telescope after reversal, detected by means of two very delicate levels attached to the telescope; and the last term a small correction for the *difference* in the atmospheric refraction affecting the rays of light coming from the two stars. It might be noticed that if the two stars are at *exactly* the same zenith-distance, and the instrument is reversed without disturbing the pointing, then the second, third and fourth terms each become zero in the equation above, and the latitude is simply the mean of the declinations of the two stars, or the declination of the zenith, as may be seen by referring to Fig. 1.

The percentage of nights upon which observations were obtained, during the first five years at the various stations, is given in the following table:

PERCENTAGE OF OBSERVING NIGHTS

	Per Cent.		Per Cent.
Mizusawa	50	Gaithersburg	42
Tschardjui	35	Cincinnati	32
Carloforte	72	Ukiah	48

The conditions at Carloforte, in the Mediterranean Sea, must be almost ideal from an astronomical standpoint, still the above tabulation can not be taken as a true index of the weather at the stations. At Carloforte and at Mizusawa two observers are constantly employed, and probably nearly every favorable night is utilized. At the other stations, where all the observations are made by a single observer, some favorable nights must of necessity be allowed to pass. At Ukiah, for instance, the percentage could be increased by at least ten, perhaps fifteen, if two observers were employed. In considering the above table, the further fact should be taken into consideration that Professor Porter, who makes the observations at Cincinnati, has many other duties in connection with his position as director of the Cincinnati Observatory and professor of astronomy in the University of Cincinnati. We should also consider the still further fact that at some stations—for instance, Mizusawa—many nights are rendered incomplete by fog or clouds, and a night upon which only one pair is obtained enters into the above tabulation with the same weight as a complete night of sixteen pairs.

On account of the uncertainties of the weather it seldom happens that observations are obtained at all the stations on the same night—and a complete set of sixteen determinations at all stations on the same night is indeed a rare event. During the first five years that observations were made, there were but nineteen nights upon which *some* observations were obtained at all the stations, and not a single night on which a complete set of sixteen determinations was obtained at every station.

This seems a little strange at first thought, but a simple computation according to the principles of probability shows that such a result should be expected. Let us ask, first, What is the probability of obtaining at least some observations at each station on the same night? If we assume that observations are made on the average on fifty per cent. of the nights, then the probability of obtaining observations at any one station on any particular night will be one half, and manifestly the probability of obtaining observations at two stations on the same night will be $\frac{1}{2} \times \frac{1}{2}$, or $\frac{1}{4}$, and the probability of obtaining observations at three stations on the same night $\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2}$, and the probability of obtaining observations at six stations $(\frac{1}{2})^6 = \frac{1}{64}$.

Observations would therefore be made at all six stations on the same night on an average of once in every sixty-four nights. The assumption, however, that observations are made upon fifty per cent. of the nights is somewhat in error, the true percentage being almost exactly 46.5. The probability of this event occurring would be therefore $(^{465}/_{1000})$,[6] which equals $1/99$. The event would occur on an average therefore of once in every ninety-nine days, or nineteen times during the five years under consideration. This result is in exact agreement with the observed number.[4]

Let us now ask, What is the probability of obtaining a complete night's work at all six stations on any particular night? The ratio between the number of complete nights and the total of nights is not given in the published results, but is probably not far from one half. At Ukiah about sixty per cent. of the nights upon which observations are made are complete, but the percentage is known to be less at some of the other stations. If now we assume that observations are made upon fifty per cent. of the nights, and fifty per cent. of these are complete, then a process of reasoning similar to that just used will bring us to the result that the probability of the occurrence of the event under consideration is $(1/64)^2 = 1/4096$. That is to say, a complete night's work will be obtained at all six stations on an average, in round numbers, of once in every 4,000 nights, or once in about eleven years, so that it is not at all surprising that this rare event did not occur at all during the first five years of observations.[5]

The observations made during the first five years after the international latitude stations were established, and the results deduced from them, have been published in two quarto volumes.[6] These observations show periodic changes in the latitude similar to those found from earlier observations. The results obtained at the various stations, from the beginning of 1902 to the end of 1905, are represented graphically in Fig. 5, taken from the second volume just mentioned. All the observations obtained at each station during a certain period, about a month, are combined into an average value, these mean results are plotted, and represented in the figure by the small circles. The small figures standing adjacent to the circles indicate the number of

[4] The exact method of computing this probability is, of course, to take the product of the six separate probabilities rather than the sixth power of the average probability. The result comes out sixteen rather than nineteen.

[5] If more exact figures were used in this computation it is certain that the probability of this event would be much reduced, perhaps by nearly one half, so that the event would not occur more than once in twenty years.

[6] *Resultate des Internationalen Breitendienstes.* Band I. (1903), von Th. Albrecht. Band II. (1906), von Th. Albrecht und B. Wanach. *Centralbureau der Internationalen Erdmessung;* neue Folge der Veröffentlichungen, Nos. 8 und 13. A review of these volumes was published by the writer in *Publications of the Astronomical Society of the Pacific,* Vol. 19, pp. 139–58.

observations entering into each average. The small circles are connected by straight lines. The smooth curves in each case are obtained by combining, by means of a mathematical analysis, the results at all

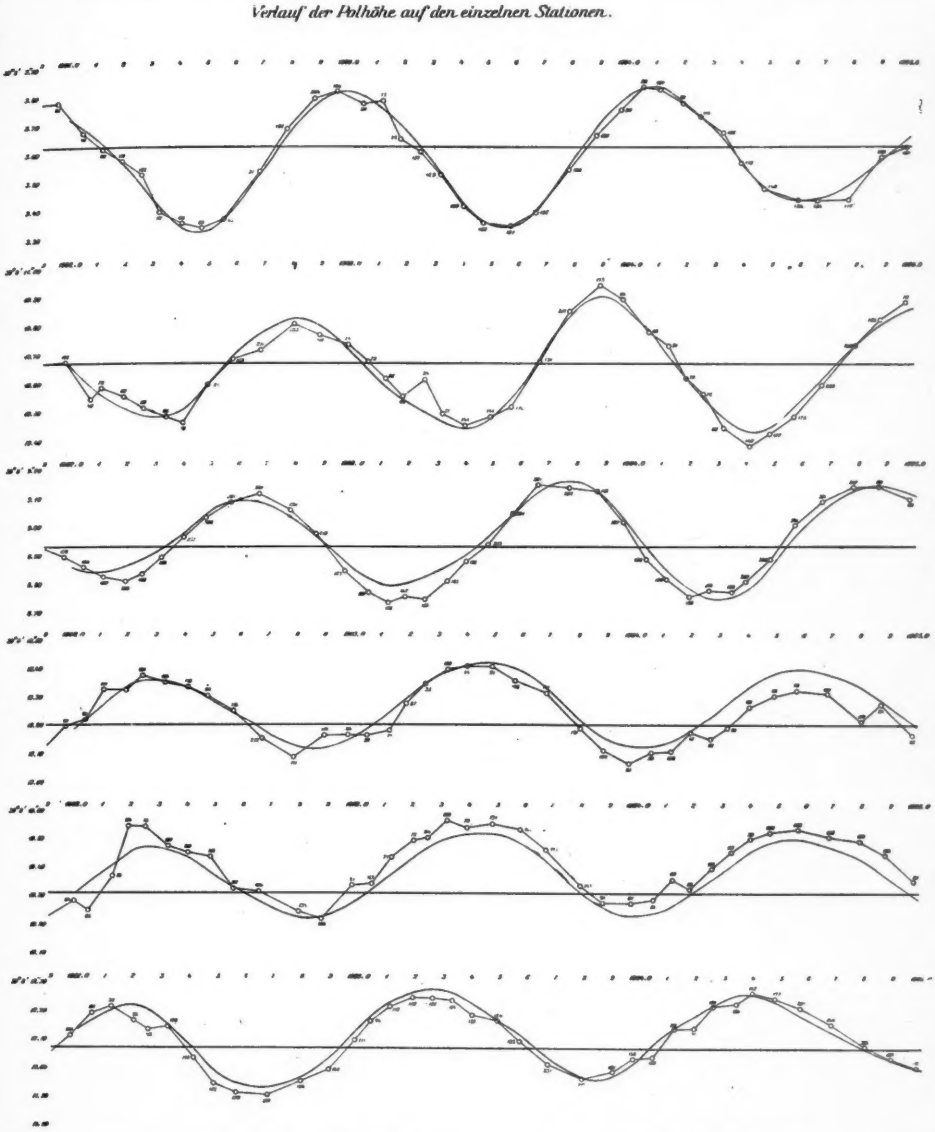


FIG. 5. Observations taken at Mizusawa, Tschardjui, Carloforte, Gaithersburg, Cincinnati, Ukiah. (Reading from the top, down.)

of the stations into a general result, and then from this general result computing the variation of the latitude for each individual station. The vertical distance between any small circle and the smooth curve will be, very nearly, the actual error of the average result represented

by the circle. The station where these vertical distances are the smallest will, in general, have obtained the most accurate results. An inspection of the figure shows that the best agreement was obtained at Mizusawa. It is rather significant that at Carleforte, where more than twice as many observations are obtained than at some of the other stations, and the meteorological conditions are exceptionally fine, yet the agreement between the observed and the computed curves is not so close as at some other stations. This is a good illustration of the precept that, in general, little or nothing is to be gained by increasing beyond a certain moderate amount the number of observations made with the same instrument under similar circumstances. In fact it is quite possible that just as good results could be obtained by limiting the number of observations taken at each station to a monthly average of a hundred or thereabouts.

As Tschardjui and Ukiah are separated by nearly 180° of longitude, the curve of the one is almost the counterpart of the other. It may be seen from Fig. 5 that the maximum change in the latitude, during the time represented, is less than 0″.5, which corresponds to about fifty feet on the surface of the earth. The observatory then apparently swings back and forth in the meridian to a distance of twenty-five feet on either side of the mean position.

Having now the actual observed variations in the latitude at six different stations, separated widely in longitude, it is a comparatively simple problem in mathematical analysis to compute what the actual motion of the pole, with respect to its mean position, must be in order to produce the observed changes in the latitudes. If the difference between an instantaneous value of the latitude and the mean value be represented by $\Delta\phi$; the rectangular coordinates of the instantaneous pole, with respect to the mean position of the pole, by x and y; and the longitude of the observing station by λ; then the following equation, the derivation of which is given in the review mentioned above, may be written,

$$\Delta\phi = x \cos \lambda + y \sin \lambda.$$

Early investigations showed that the observations were not represented to the highest degree of accuracy by this equation and Dr. Kimura, the Japanese astronomer, suggested the addition to the equation of a third term, z, independent of the longitude. The observations are satisfied much better by an equation of this form, and z turns out to be a small variable quantity of an annual period. No satisfactory physical explanation of this term has as yet been given. Several have been suggested, one of which is that perhaps there is a small annual shift in the position of the center of gravity of the earth.

In order to solve the problem connected with this term, two additional latitude stations were established in the southern hemisphere in

1906. They are both located in south latitude 31° 55′—one at Bayswater, near Perth, West Australia, and the other at Oncativo, in the Argentine Republic, about forty-five miles from the National Observatory at Cordoba.[7] Definite results from these observations have not yet been obtained, but Dr. Albrecht has recently published a short note stating that a provisional reduction of the observations obtained at the two southern stations shows that z has the *same sign* at the south parallel as at the north, and probably the same magnitude. If this is true the hypothesis of a shift in the center of gravity of the earth must be abandoned. This term is zero about ten days before the equinoxes and reaches its maximum values, $-0''.048$ and $+0''.044$, about ten days before the summer and winter solstices, respectively. These facts would seem to favor the meteorological explanation of origin of this term.

The motion of the earth's north pole, from the time the International Latitude Stations were established in the fall of 1899 to the be-

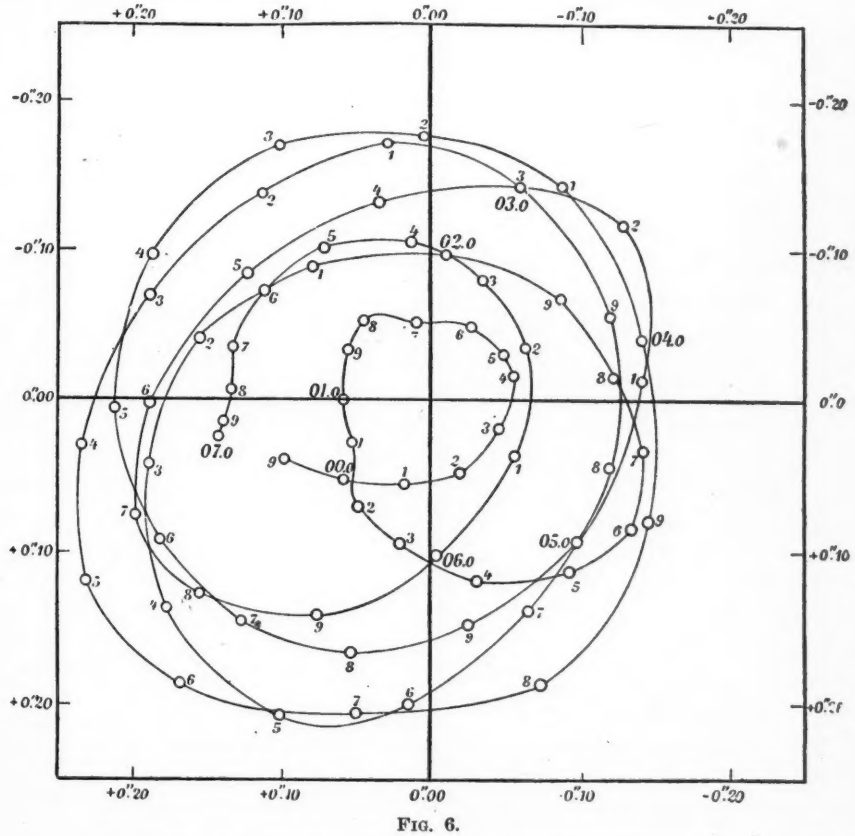


FIG. 6.

[7] In addition to these eight stations under the International Geodetic Association regular observations for latitude are made at Poulkova, Russia, in latitude + 59° 46′; at Leiden, + 52° 9′; and at Tokio, + 35° 39′.

ginning of 1907 is represented in Fig. 6 taken from the *Astronomische Nachrichten,* No. 4187. The large square represents a piece of ground fifty feet on a side. The small circles represent the position of the pole for each tenth of a year beginning with 1899.9 and ending with 1907.0. By starting at the beginning and following out the motion of the pole a roughly spiral path is found with a clearly marked period of about seven years, the position of the pole at the beginning of 1907 almost coinciding with the initial position, 1899.9.

The observations made at the International Latitude Observatories have determined the motion of the pole with a degree of refinement and continuity never before attained, and it is now found that the laws deduced by Chandler fifteen years ago are no longer sufficient to accurately represent the observed motion. Dr. Kimura has recently made a harmonic analysis of the variation of latitude and finds, in addition to the two principal motions of periods of fourteen months and one year found by Chandler, two smaller motions with periods of 0.75 and 0.6 of a year. Kimura also finds that the principal motion of fourteen months is in an ellipse and not in a circle as found by Chandler, the interpretation of which would be, that the equator is an ellipse and not a circle, if we assume the earth to be made up of homogeneous layers, or, in technical language, that the equatorial moments of inertia are unequal.

The change of latitude being so very small is, of course, of no consequence whatever to the navigator who has to determine his position at sea. It is, however, of great interest and importance from a scientific standpoint, and it is hoped that the work at the various stations may be carried on long enough to make a definitive determination of the laws of the polar motion possible, so that a mathematical formula may be constructed from which the position of the pole, or the latitude of any place, may be computed for any time past or future.

One way in which the variation of latitude might have political or commercial significance is in cases where a certain parallel is designated as the boundary line between two countries, states or counties. For instance, the forty-ninth parallel is, for a portion of the distance, the boundary line between the United States and the Dominion of Canada. If any question should be raised, however, a court of arbitration would probably decide that, inasmuch as the actual line shifts its position, the one already established, if not egregiously in error, should continue to be considered the boundary line. A case similar to this has recently been decided by the courts of California. The boundary line between Mendocino and Trinity counties is defined as being the fortieth parallel of latitude. When the counties were first established a surveyor was employed to locate this line, but some score or so of years afterward other surveyors found that the established line lay about two miles too far south. Thereupon Mendocino County brought suit against Trinity

County to have this two-mile strip taken from the latter and added to the former. After dragging through the courts for a number of years the matter was finally decided in favor of Trinity County, the argument being that, inasmuch as it is impossible, by ordinary processes of surveying, to locate the parallel with absolute accuracy, the original survey, made by due process of law and accepted by both counties, although admittedly largely in error, should remain the official boundary line. The amount of territory, mountainous and sparsely settled, is a comparatively small part of either county, Mendocino County being nearly as large as the state of Connecticut. The question was, however, of considerable importance to the property owners of the two-mile strip. After the land was claimed by Mendocino County, it was assessed and taxed by both counties, and the taxpayers who cast their lot with Mendocino County now have several years of back taxes to pay in Trinity County.

Doubtless most of the readers of this article have already wondered what may be the cause of the shifting of the earth's axis. In 1765, Euler, a famous Swiss mathematician, demonstrated, as a proposition in dynamics, that if a free rigid oblate spheroid rotates about an axis which differs slightly from the axis of figure, or shortest axis, then the axis of figure will revolve about the axis of rotation in a period the length of which will depend upon several factors. He computed that, if the assumed conditions obtained for the earth, then the period of revolution of the axis of figure about the axis of rotation would be 306 days. Obviously, however, the earth is not rigid; the oceans are quite plastic and the ground itself is possessed of some elasticity. Professor Newcomb computed some years ago that, if we assume the earth as a whole to possess the rigidity of steel, then the period of revolution of the one axis about the other would be 441 days, as against 306 days found by Euler on the assumption that the earth is perfectly rigid. The actual observed period is fourteen months, or 427 days, and the legitimate conclusion to be drawn is that the earth as a whole is somewhat more rigid than steel—a conclusion that agrees with that derived by Lord Kelvin and others from entirely different considerations.

Now the question arises, Why does the earth not rotate upon its shortest axis? The explanation is simple. If the earth ever did rotate upon its shortest axis it could not continue to do so because of the shifting of matter upon and within the surface. Winds, rains, rivers and ocean currents are ceaselessly transporting matter from point to point, and during the winter great masses of snow and ice accumulate in the temperate and frigid zones only to disappear again in the summer. Although these effects will, to a large extent, neutralize each other, the sum total can not be other than to produce at least a theoretical lop-sidedness to the earth; and as soon as this takes place there must be a shifting of the axis of rotation. The time of revolution of

the one axis about the other could be accurately computed if the exact form of the earth, the structure of the earth's interior and its coefficient of elasticity were known.

In addition there are other phenomena, namely, volcanoes and earthquakes, through which considerable quantities of matter may be displaced. That the amplitude of the polar motion might be affected by earthquakes was pointed out by Professor Milne ten or fifteen years ago and a French scientist has more recently compiled a table showing the number of severe earthquakes each year and the amplitude of the polar displacement. A rough proportionality between the two seems to exist, that is, the greater the number of earthquakes each year the greater the amplitude of the polar displacement. Such results, however, are to be taken with several grains of allowance. The term "severe earthquakes" is rather indefinite and by modifying its definition quite a variety of results may be obtained from the given data. It might be pointed out that in 1906, the year of the great earthquakes in California and Chile, the amplitude of the polar displacement was small.

We have then a rational explanation of the phenomenon of the variation of latitude. The axis upon which the earth rotates is not in exact coincidence with the shortest axis; such being the case, according to the principles of dynamics, the axis of figure must revolve around the axis of rotation giving rise to the changes of latitude. But on account of the changes incessantly taking place in the distribution of matter upon the earth's surface, and perhaps also within the surface, the amplitude of the polar displacement, and perhaps the principal period of revolution of the one axis about the other, are changeable, the changes taking place in a rather complicated way according to laws as yet not fully determined.

In connection with this explanation we should not lose sight of the fact that all the material moved through meteorological, volcanic and seismic agencies is probably almost infinitesimal as compared with the total mass of the earth, and no one, so far as I know, has as yet shown that the shifting masses are sufficient in magnitude to properly account for the observed annual and other unexplained components of the polar motion.

Indeed, if one desires to follow the path of least resistance, he might abandon the above explanation altogether and adopt the one given by a colored preacher living in the oil region of Texas, who met some brethren at the corner grocery one day and delivered himself of the following explanation of this puzzling scientific phenomenon:

Ah see by de papers dat de urf's axis am a wobbling an' dey dunno wat fo'. But ah know wat makes de urf's axis wobble. Do you see all dis oil dese men am a takin' out of de urf? Well wat do you spose de good Lord put dat oil in dere fo'? Wy to grease de axis wif, of couse, an' when dey take it all out, wat else can de axis do but to wobble an' to squeak?

DESERT SCENES IN ZACATECAS

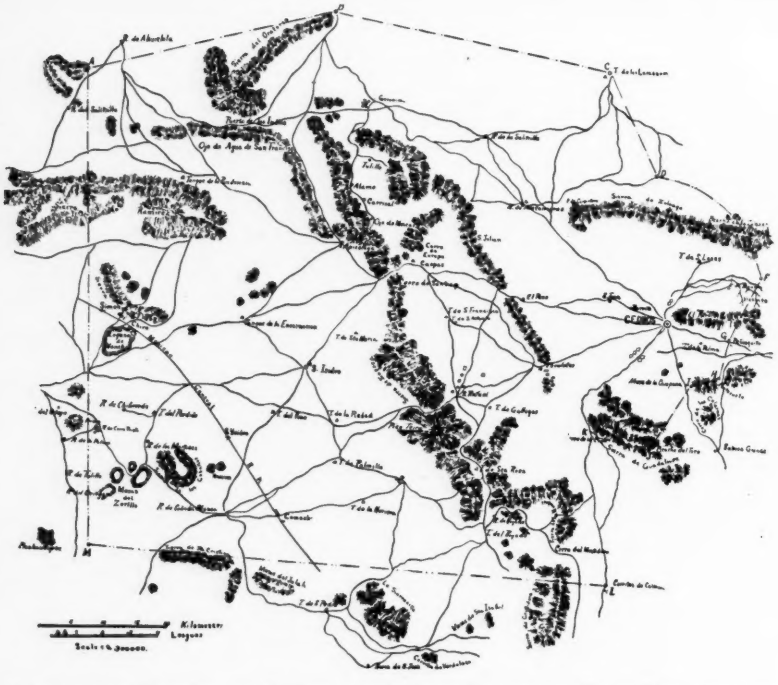
By Professor J. E. KIRKWOOD
UNIVERSITY OF MONTANA

ABOUT 400,000 square miles of desert lie south and west of the Rio Grande. Much of this vast area occupies the great table-land, bounded east and west by long mountain ranges and reaching southward several hundred miles, where it becomes broken by more fertile areas; all this being, in fact, a continuation of the great south-western desert region of the United States which prevails from Texas to California. The aspects of its southern extension vary with local conditions within certain limits, and with its lowering latitude new elements enter into its composition, but on the other hand many of the features characteristic of a Texas or an Arizona landscape are conspicuous in its geological formations, its fauna and its flora. This region has, however, certain significant peculiarities which give the central Mexican plateau a character of its own.

Typically representative of the conditions on much of this great plateau is the northern part of the state of Zacatecas. Traversed by fragmentary mountain ranges with a general trend from northwest to southeast, only in a few places do its plains stretch level to the horizon. On every hand the skyline is formed by the heaving back of some ridge or group of mountains whose summits rise from 1,000 to 4,000 feet above the plain. The plain itself is 6,000 feet elevation, more or less, and the mountains appear as if almost submerged in it. Here and there are lower ranges whose heads are scarcely lifted above the plain and whose softly rounded outlines show that leveling forces have long been at work upon them, or that their softer materials have more readily yielded to eroding forces. Other peaks rise higher and a few of these are rugged and sharp with steep declivities, but for the most part the evenly rounded outline prevails.

The more or less isolated ranges, the Sierras of the Potrero, the Zuloaga, Zapoca, Guadaloupe, Oratorio, Ramirez, Chivo, Caballos, etc., are all on an area some sixty by seventy miles in extent, which constitutes the Hacienda de Cedros, a corner of which the Mexican Central Railroad crosses southeast of Torreon between Rivas and Carlos. This Hacienda, which lies mostly to the east of the sun-baked village of Camacho, extends also to the west fully twenty miles. An interesting estate and sufficiently large from an American standpoint it is, but one of many of its kind in Mexico, managed in a feudal way. It is to this particular region that the accompanying discussion pertains.

Looking westward, far across the broad Camacho plain, standing



MAP OF THE HACIENDA DE CEDROS, a private estate of over two million acres, on which dwell some two thousand people.

well up on the horizon are the high Mesas del Zorillo. Their broad level tops lie in the same plane, at their borders a sheer descent is visible to the point where the talus slope begins and slants off in graceful lines to the rolling lands below. But such configurations are rare in that region. Here and there what is left of that stratum which forms the high floor of these Mesas may be visible, but only as vestiges, for they have mostly disappeared.

Standing at the edge of one of these wide plains and looking across, one may survey at a glance twenty to forty miles of mountain barrier along the opposite side, thirty to fifty miles away. Deep scalloped with cañons and ravines which divide and subdivide into successively smaller branches as we follow their course upwards, they are ultimately lost in the rounded brow of the mountain. Below the steeper slopes the low-lying, far-outreaching butresses of the range finally sink into the plain. At the mouths of the cañons, broad fans of silt, gravel and other detritus from the heights above, spread out and meet their neighbors on the right and left until a long, slightly undulating footslope is formed, and gradually merge into the floor of the valley. Thus the wide valley is gradually being made wider by the building up of its floor, which is the accumulation of ages of the wash from the mountains; the nature of the process is obvious. Where a deep arroyo cuts down through the land a section of the deposit shows

in places stratification of clay, sand and gravel. Here and there a well is bored and the same story is told. Every valley between these mountain ranges presents the same features, a gentle slope for miles from either side, so gentle that in walking over it one hardly realizes that it is not level, and in the center is—not a stream—but a shallow basin, frequently lined with salty incrustation. Such is the character of the Bolsón, as it is called, which is also a marked feature in the physiography of southern Arizona.

Into these basins the arroyos pour the floods from the mountains. One finds the arroyo in the higher parts of the plain nearer the mountain where the steeper incline gives more velocity and erosive force to the stream. Lateral valleys which lie between high slopes usually develop the arroyo to a marked degree. The deep basin between the ridges, filled with the detrital wash from the slopes, is readily eroded by the swift streams which are produced frequently by the torrential rains of these regions. Running lengthwise through the midst of an apparently level valley floor, these arroyos are often invisible a few feet away, and the traveler may be entirely unconscious of the presence of a ditch thirty feet deep and possibly fifty wide, with perpendicular walls, hardly fifty paces away. The walls of these arroyos are being constantly undermined, and the materials, caving into the channel, are carried out with the rest of the wash; at the same time the head of the arroyo is receding toward the higher land and the channel becomes more and more shallow as the underlying rock comes nearer the surface. As the arroyo extends out into the plain its fall becomes less, the power of erosion by the water decreases and the channel is finally lost on the lower slope.

Thus the composition of the mountains is responsible for the composition of the valley floor. Limestone is the predominating material. Rocks of igneous origin are less conspicuous, but are present, and mineral-bearing veins are plentiful. Occasionally heavy formations of calcareous tufa may be found where springs issue from the hills, as at the village of Cedros, situated at the end of a short range. In deep and sheltered ditches salts collect on the clay and hang in slender glistening crystals to its surface. The ooze of calcium solutions is everywhere visible in the formation of caliche, which forms a hard, impervious and impenetrable layer on or near the surface of the ground. Here and there it cements together stones and gravel in a solid mass, resistant to weathering and erosion.

But few springs are found and these usually at the foot of the higher slopes. At the western end of a small range, the Sierra del Potrero, water comes to the surface in numbers of strong springs, and on this oasis is built the village of Cedros, the administrative seat of the Hacienda of the Cedars. From the limestone rock, cropping out on the toe of the range, the springs issue forth. One at least of these is warm,

SOTOL ON THE HACIENDA DE SANTA INEZ. Photo by F. E. Lloyd.

the others cold; some feed a small rivulet, across which one might step with ease, that passes through a series of reservoirs and is used in irrigating the gardens, some supply the baths, and others the troughs where the cattle come to drink.

But this wealth of water, for wealth it is in such a country, is not general. One would go far to find so splendid a supply as feeds the industries of this place. Here and there wells are sunk in the valleys and water is found at a depth of forty feet more or less, but often drilling goes much deeper without finding any.

The sites of these springs are here, as everywhere else in deserts, oases of fertility, visible sometimes a day's journey across the broad valleys, and marked in the broad expanse of desert landscape by dark tops of huge cottonwoods, and the light reflected from the white-washed walls of adobe houses. The number and quality of the springs determine the size of the hamlet and sometimes the nature of its operations. Upon arrival we may find also ash and pepper trees, pecans, avocadoes, figs, pomegranates, apples and grapes, rows of magueys and hedges of tuna-bearing nopáls. Onions, garlics and

chilis are the principal garden crops, and flowers (poppies, asters, roses, etc.) in pots or beds in the patios or dooryards of nearly all dwellings, however humble. Fields of corn and barley, with *calabasas* (squashes), are scattered about the plain not far away, where crops are matured in the short season of the summer rains. Their corn planted in July is harvested in October, its growth hastened by irrigation of a primitive sort; running a ditch along the face of the slope, the ranchero collects the run-off from the rains and directs it on to his field. On some of these fields corn grows to the height of ten feet with a degree of luxuriance that would gladden the heart of a northern farmer.

Although no permanent streams of any consequence exist, yet the rapid drainage of the land makes feasible a mode of existence otherwise impossible. The herdsman pushes out away from walls and springs and establishes himself in the midst of the desert. Choosing a place where the land lies to form a basin or wide valley, he throws a dam across the mouth and collects the run-off from a large area. For this purpose a gently sloping drainage basin is preferred, else the labor of building the dam will come to naught in a few years by the reservoir's becoming filled with silt and drift; moreover, the rushing torrent may cut through the embankment and drain the tank dry. I have seen old tanks which had been filled to a depth of fifteen feet or more, and as the earthen dam was finally cut through, the later floods had sluiced down an arroyo through the flat sedimentary plain above. So the tanks in such situations are short lived, but where fed by the gentle drainage of a gravelly plain they may last indefinitely and supply water the year round to large herds. Frequently these tanks hold water covering several acres at the height of the dry season, and when at its deepest it may assume the proportions of a small lake. Some of the dams are strong and well-built structures of stone masonry a half mile or more in length and ten to twenty feet in height. To the "tanques" come the horses, the mules, the burros, the sheep, the goats and every other animal of the desert; they drink the turbid liquid, they wade in it, they bathe in it, they discharge into it, and all around the margin is a fringe of greenish drift and scum, but it is water in a thirsty land and man is grateful for it. It is the objective camping point in the day's travels and at noonday the cool shade on its banks is the favorite resting-place for man and beast.

From one to two and a half feet of rain falls on this land in a year, depending partly on the altitude and local conditions. Records of rainfall at Chihuahua and San Luis Potosi show 10.86 and 10.41 inches, respectively, for one year (1901), and at the city of Zacatecas the average for ten years (1897–1907) was thirty-one and a half inches. The precipitation at Cedros for one year (1907–8) was about eighteen inches.

PALMA CHINA (*Yucca australis*) IN THE VILLAGE OF CEDROS. Photo by E. A. Crane.

The heavy rains, sometimes as much as an inch in a few hours, run off with great rapidity through the drainage channels and twenty-four hours later the sides of the mountains and the footslopes appear as if not having known a rain in six months. Here and there in the bottoms of the cañons a pocket in the rock holds a gallon or two of sweet pure water, and out upon the plain pools may linger for a few days on the clay.

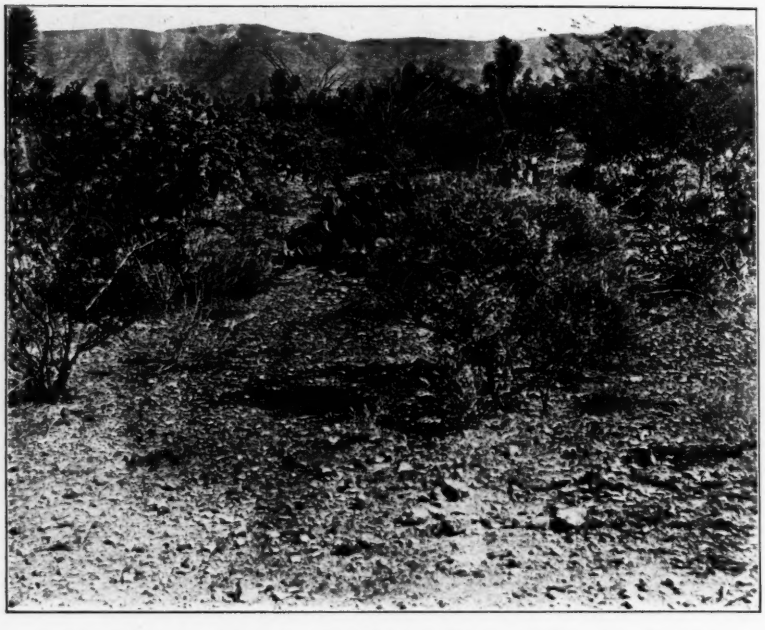
Here the summer months are the months of rain, but in most months of the year a little rain may be had. As springtime advances clouds may be seen along the distant slopes and among the peaks with a trailing haze of rain beneath. Though in the summer-time the rain clouds are partial to the highlands, yet more often do they wander out across the plain. Scarce a day of summer passes but showers may be seen falling on some part of the landscape, but the amount falling on any particular area is relatively small.

The isolation of these places is intense. The light of midday dazzles the eyes as it is reflected from the walls of the houses, the dust of the road, or the whitish soil of hill or valley. Heat is a liberal accompaniment of the fierce glare of light, as blistered lips may abundantly testify after a few hours riding across the desert. The Mexican knows the value of his broad-brimmed sombrero and is seldom to be found without it, if indeed we may induce him to leave the shade of the tree or the dark interior of his adobe dwelling at the middle of the day. But the shade, even the thin shade of the mesquite, is a place of comfort, affording some shelter from the direct rays of the sun. Even alongside a thermometer registering over 100° in the shade, no discomfort may be felt in the thin and relatively dry air of this climate.

The most suggestive feature of the desert is its vegetation and the variety of the plants which it supports. The great number of species which by some peculiar fitness of their own are able to maintain themselves in the midst of seemingly impossible conditions, must certainly impress one accustomed to the abundant vegetation of the green fields and woodlands of the better-watered sections of the country, though the number of individuals of a race may be considerably less. This is not true of all species, but the fact is quite patent to any one who has seen even a little of desert vegetation, having in mind the almost impenetrable vegetation of some of our northern woodlands. Across the desert of Zacatecas one may ride in any direction, limited only by the perpendicular banks of arroyos, or mountain barriers. The floor of the desert here also is bare and clean for the most part, which means a paucity of herbaceous plants. Such herbaceous forms as do exist are found usually in shaded situations, under the shelter of woody perennials.

The vegetation of this region as it appears to one at a casual glance seems to be composed of Yuccas, shrubs and small trees, Agaves and cacti and these constitute the predominant features of the plant life in varied arrangements and conditions.

The most conspicuous element in this vegetation is the palma, so called, which may be seen on every hand. Two kinds are usually met with; one a straight-stemmed plant, six to ten feet in height, with a crown of stiff radiating sword-like leaves, much prized for the fiber or ixtli which it yields. This plant, *Samuela carnerosana,* which the native calls palma zamandoca, grows in great abundance on the higher lands, from the upper footslopes a thousand feet up the mountainside. On the high rolling land south of Saltillo, from Carneros to Fraile and beyond, thousands of acres are covered with this splendid plant. In March and April they are in full bloom and one may go far to find a more pleasing picture than these tall plants with their erect panicles of creamy-white flowers, two or three feet in height. This plant grows so



A GOOD COLLECTION OF DESERT PLANTS: VEGETATION OF THE PLAIN.
Photo by F. E. Lloyd.

slowly that the increment of one season can not be marked without precise measurements, but year by year the lower leaves of the foliage crown die and add to the thatch of dry leaves that cover the trunk below. The trunk itself is six inches to a foot in diameter, a mass of spongy tissue with a more dense outer rind. Of these stems the peon makes fences, or sets them palisade-like for the walls of his hut, or hollows them out for bee-hives. The leaves of the plant make the most convenient thatch for his hut, and from the fibers of its leaves he makes ropes and sundry other articles of convenience. Palma china, as the native calls it, known to botany as *Yucca australis,* is a close relative of the preceding and often occurs in the same situations. Usually, however, this plant does not ascend to the heights attained by its neighbor, but is a native of the wide valley lands, where it often occurs in great profusion as at Palmas Grandes, a few miles west of Mazapil, and again on the footslopes some twenty miles east of Camacho. This Yucca is the most striking of all the plants seen on this desert. Reaching a height of 35 to 40 feet, and having a trunk diameter of two to three feet, its upper portion is divided into straggling branches clothed for a foot or two from the tip with rigid outstanding leaves a foot and a half long. The branching of palma china is never symmetrical, but usually both trunk and branches are contorted and arched in various directions. Occasionally one is found straight and tall and beautiful,

such as grew by a peon's hut in the village of Cedros, and one which was found on the plain near Symón was as grand a tree as an oak of two centuries and probably not much younger. This magnificent palma must have been close to forty feet in height, with a hundred branches which filled out the hemispherical top with symmetry and beauty. The trunk of this palma was near three feet in diameter four feet from the ground, and its thickened base below was not far from six feet across. The flower cluster of this plant is about three feet long and the creamy flowers which abound in June are much prized by the people as food. This plant also yields fiber, which, however, is not so generally used as that of its neighbor, owing doubtless to the abundance of the latter, which has longer and more accessible leaves. Some of the other desert plants less conspicuous than the Yuccas are hardly less interesting. In numbers the Maguey and its family outrank almost everything else. From *Agave americana* down to *A. lechuguilla* and *Hechtia* they are everywhere abundant. While the huge pulque maguey is found in this region at least only in cultivation, its lesser relatives are on a thousand hills, sometimes leaving little room for anything else to grow. Three species of Agave are abundant. Two of these, *A. lechuguilla* and *A. falcáta,* are never found on the level plain, but as soon as one begins the ascent of the low ridges which rise but little above the valley he is almost sure to encounter *A. lechuguilla.* We may say encounter advisedly, for their leaves are as so many daggers set at all angles to impale the unwary. The rigid leaves about a foot long are armed with terminal spines as sharp as needles and as strong as nails. These in places, especially on the low limestone ridges, are so numerous that one with difficulty can make his way through. In June this plant is at the height of its flowering season and over large areas the flowering shoots, ten to twelve feet tall, are everywhere conspicuous. The stems of last year have fallen, and the new ones soon ripen their seed and terminate the life of the plant. The leaves of this plant are especially valuable for fiber and it is one of the most important of native Mexican plants. From it the native also obtains amole, the short stem and leaf bases, which, when crushed, has marked saponaceous properties, and seems to justify the esteem in which it is held, if one may judge by results. *A. falcata* occupies the slopes of the ridges, but is rare as compared with *A. lechuguilla.* Its flower stalk is smaller on the whole than that of its neighbor and its flowers much darker colored. Its sickle-shaped leaves are pointed inward and it is, therefore, not nearly so unpleasant to meet as Lechuguilla. But its fiber is little used, probably owing to the scarcity of the plant and the great abundance of the other species which is more easily worked.

Agave asperrima is one of the plants which the traveler first notices in the desert of Zacatecas. Its bluish-green leaves are usually less than three feet in length as it grows in the desert, but are sharply armed

PEON HABITATIONS IN THE DESERT. Photo by F. E. Lloyd.

with stout spines both terminal and lateral, which make them formidable objects to meet. These plants spread by stolons and form impenetrable masses where they monopolize the ground. This agave grows in greatest abundance on the plain, where it frequently impedes the progress of a horseman quite effectually. It also spreads upward on the ridges and in the cañons to points a thousand feet above the plain. Its flowering season is in June, though it loiters along in this business through the whole summer. The flowering shoot is similar to that of *A. americana,* but hardly exceeds fifteen feet in height. But these great flowering shoots are of great interest in their strength and beauty, looming up against the sky on the crest of some ridge, and not the least in the fact that this huge inflorescence represents the culminating vital activity of the whole life of the plant. Slowly through the years the materials have been gathering for this particular task, and finally in a few short weeks of summer the supreme work is consummated, and the great candelabrum of branches stands forth with its hundreds of seed capsules, while the erstwhile luxuriant leaves are sere and withered, their substance, as indeed the whole life of the plant, sacrificed to this one supreme effort toward the propagation of its kind. When in bloom the inflorescence is surrounded by myriads of flies and other insects attracted by the abundant nectar which the flowers secrete. These flowers in press, if not killed, continue for days to produce the viscid sweetish fluid which the natives collect and call *miél* or honey. When the seeds are ripe the pod splits down from above

and spreads apart slightly, so that a few seeds are easily shaken out by a gust of wind. The inflorescence, though dead, may stand for a year or more, and the seeds that it bears may be scattered over a wide area.

Before this plant comes into bloom the tender apex of the short stem is often used as food. Out in isolated places among the mountains one may come upon a rude circle of heavy stones bordering a shallow pit. The Mexican would say that here they were preparing *quiote* by taking the hearts of the magueys and roasting them in the pit. Upon further inquiry he will say that these morsels are covered with earth and stones and the fire built over them and kept for some hours. The older leaves yield a fiber for cordage, though this plant to a less degree than its larger relative, *A. americana.* Many uses are found for the maguey; in fact hardly any other plant of Mexico serves the people in so many ways as this one. It provides food and drink, it yields fine strong fibers for ropes, fabrics and other articles. It has served in the manufacture of paper and enters into the construction of fences and buildings. It formerly found use in religious rites and was part of the material of weapons.

As ornamental plants the cultivated magueys are hard to beat. During its fifteen years' or more life it produces relatively few leaves, but towards the close of its span of years one hundred or more of these may be in evidence, each somewhat narrow, six to ten feet in length and often weighing as much as one hundred pounds. Most of them are a dull dark green, some are margined with yellow or yellowish green. They are often planted as hedges or borders, and as such they are very attractive to look at. The short stem which in all the years has not attained a height of two feet now suddenly shoots up to thirty feet, its outstanding branches in symmetrical order enhancing its dignity and beauty beyond that of most other plants.

On the slopes of many foothills that rise from the edge of the desert plain and often on the higher slopes in great profusion, one finds a stately plant which is always conspicuous and always beautiful. Something about the sotól makes it especially attractive, with its pale green leaves an inch wide and a yard long, the tips of which often overtop a man's head. But these leaves, though beautiful to look upon, are well armed against any invader by means of many forward set teeth along their margins. In fact, a leaf of *Dasylirion* is like a piece of double-edged band saw.

Under the hot sun of May and June the flower stalk ascends from the center of the crown of leaves and carries its topmost flowers to twice the height of the horseman riding by. These flowers, unlike those of the maguey, are small and borne on a long and slender, though compact panicle; they are monœcious, therefore not all the tall stems

PICO TEIRA FROM TANQUE DE LA PIEDÁD. Photo by F. E. Lloyd.

are destined to bear the small triangular fruits that often remain the following winter on the stalk that bore them.

This plant, besides being one of the most attractive of the whole desert flora, is not without its uses, both legitimate and otherwise. From the leaves of sotol the natives weave mats and various other articles of utility. They split the long leaves into narrow strips which they weave into hats. But this plant, like the maguey, also furnishes food and drink. The central cabbage-like bud is cooked and eaten. This central bud, and the thick top of the stem below it, are used much in the manufacture of a fiery liquor called Sotól, of rank intoxicating power.

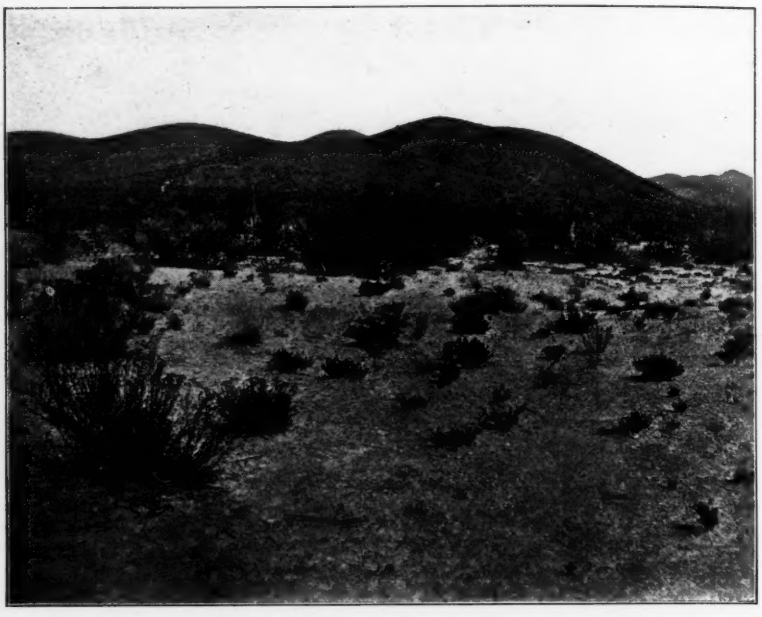
While the plants above cited are striking and characteristic features of this desert vegetation, yet even more common and more characteristic of deserts in general are the cacti, which abound in species and individuals. *Cactus, Echinocactus, Cereus, Echinocereus, Mamillaria* and *Opuntias* of both divisions are everywhere. Down on the open plain the nopáls (*Platopuntias*) abound, as one soon discovers who tries to ride across country. The broad flat joints of these plants are everywhere. Here and there a cluster of bisnaga çolorada (*Echinocactus pilosus*) shows the top of its cylindrical body bristling with red spines above the low bushes, for this bisnaga, as the native calls it, does not grow very tall, five feet being about its maximum. It blooms in June and successions of yellow fruits follow the flowers. These lemon-yellow fruits about the size of a lime are possessed also of the lime's acid

properties. But this plant is not content with the lowlands, but climbs to the top of the mountain above, where I saw some of the largest of its kind.

Echinocactus ingens, like nearly all of the cacti of this desert, prefers the hills, and there its thick trunk, bristling with long straight spines, grows to a diameter of a barrel and as much as five feet in height. This bears its flowers in a furrow across the top. The pulp of this plant is said by the peons to be sweet, but one who has tasted other cacti which they eat, may be content to leave the appraisal of this delicacy to others.

The opuntias which cover the plain and mountain are of abundant interest in their variety and numbers. The cylindropuntias abound in forms of cholla, cardencia and tazajillo, according to native terminology, with spines long and sharp and barbed, which penetrate with ease thick leather leggings, and where they stick they stay. In this the tazajillo, which grows as high as a horse's back, is especially to be dreaded, with its stiff slender spines; it separates its joints at a touch and sends them along with the passer-by. Under and around these plants scores of these joints are busy taking root, though one seldom finds thickets of tazajillo. Few of these young plants really have a future before them, though there are enough of them as it is. But the cardencias, arborescent opuntias like the species mammilata, spinosior, etc., of the Arizona desert, are not so savage as the cholla, nor so unexpectedly met with as their more slender and less conspicuous relatives, the tazajillos, as above described. In its varied forms the nopál, or flat-jointed *Opuntia,* is of more interest to the native than all the other cactus forms. This is about the only kind of cactus that may serve as fodder for cattle, and it is a common sight to behold some hundreds of pounds of one of these species carried on passing ox-carts. At the last camp where these travelers rested one could probably find the remains of a fire where they had burned off the spines of a number of nopáls, which indeed is the principal diet of their oxen.

Some of these nopáls are of imposing size and aspect, but mostly they are low procumbent forms, branching out in all directions, pushing forth segment after segment from the lower forward margin of the laterally compressed joint. Along the upper margin occur the flowers and the succession of fruits in varying shades of yellow and red. Here and there at higher altitudes are forms which produce edible fruits not unlike the edible tunas which are produced under cultivation. It seems quite possible that these may be the forerunners of some of the cultivated varieties, inasmuch as the preponderance of evidence points to Mexican origin for the tuna-bearing nopáls. Again we find on the hills a small and compact species which has little to recommend it. This, *Opuntia microdasys,* has branches closely set with coarse spicules which are easily detached and are said to be a frequent cause of blindness



A DESERT LANDSCAPE IN ZACATECAS. Photo by F. E. Lloyd.

among horses and cattle. The animals nosing about among the branches of this plant for some tuft of grass or other morsel, dislodge the glochids and get them in their eyes. Every well-appointed door-yard or garden has one or more species of the cultivated cactus which produces edible fruits of which the Mexican is very fond. These are of many varieties, differing in the characters of the branches and the fruits, the latter varying in color from the deepest red to lemon color and in form entirely distinct. They form a very important item in the short list of foods upon which the poorer classes live.

In this desert region one can not but be impressed with the number and variety of the woody plants, shrubs and small trees, which are to be seen on every hand. Many of these are common in our own southwest —mezquite, ocotillo, creosote bush, *Ephedra, Condalia, Koeberlinia,* species of *Atriplex* and *Acacia* are among the most conspicuous, some are the same species and others different, and the less obvious things are, *Lippia, Buddleia, Mortonia* and many others. In all these the families of the Leguminosæ, Labiatæ and Compositæ are especially prominent, as they are elsewhere in desert regions. The shrubby growth gives color to the landscape, and in many places its whole aspect and character is due to these plants more than to the yuccas, agaves or cacti. Very few trees in this desert are more than fifteen feet high and the majority of them are much less, so that in no sense does the country seem wooded, except upon the highest ranges where pines and oaks occur.

Among these desert shrubs are some of unusual beauty. There is

Cassia wislizeni, quite common, a tall graceful bush with large panicles of orange-colored flowers, a plant which might well be valued by horticulturists of the north. All through July and August these delight the eye and stand out in conspicuous contrast with the surrounding vegetation. Pinacate they call it, though the reason is not obvious. Again if we walk out over the lower slopes not far from the banks of some arroyo we may come upon the beautiful "huisache," *Acacia farnesiana,* in full bloom if the time is summer. This plant with its small delicate leaves, its white spines, its little balls of yellow flowers scattered in profusion along the younger branches, is a beauty to behold, but the casual passer-by, if insensible to the beauty of the flowers, may perchance be attracted by their sweet and delicate perfume. Farther along in a shallow wash where the waters occasionally take their way from the higher land, appears *Chilopsis saligna* in slender graceful form, swaying to every breeze. Its clusters of red flowers need not be seen to be aware of their presence, for their sweet fragrance is borne on the breezes far beyond that of most flowers. There are few desert flowers equally conspicuous in color and perfume, and few as well supplied with either as the desert willow. But where the way leads down into the bottom of the arroyo, almost hidden under the overhanging bank, one comes unexpectedly upon the beautiful "tronadora," to use its Spanish name. Few plants of the desert are more striking in their beauty than this, with its dark, deeply compound leaves and its conspicuous cluster of orange-colored flowers, which reminds one in their form and attitude of those of the trumpet-creeper, and well it may, for it is *Tecoma stans,* a member of the same genus. If we thread along still further through the tangle of "charnís" (*Forrestiera*) with its load of mistletoe, and "junco" (*Holacantha*) and "huisache," with lacy trimmings of the vine, *Nissolia,* where the dry stream bed is flanked by *Trixis,* and sometimes Tatalencho (*Gymnosperma*) on upward to where the steep banks of the arroyo give way to less precipitous rocky slopes and into the deeper cañon beyond, *Asclepias linaria* springs from the sandy wash at our feet with its sheaf of slender stems, each capped by its umbel of white flowers. Now just to the right where a limestone cliff faces the north and receives little light from the sun that scorches the ground just beyond, is a patch of resurrection plants with their star-like forms expanded to full view by the moisture acquired from the recent shower. The day before when we passed this same way these plants had coiled themselves together into compact balls and were hardly visible in the crevices of the rock. But with the drenching shower came the resurrection to renewed activity. Near at hand some shrubs are covered with a furry growth of grayish grassy-looking plants, which upon nearer approach are seen to be a dense growth of *Tillandsia recurvata,* a sort of Florida moss, which finds in the moister air of the cañon floor or the

mountain top the conditions favorable to its growth and it attaches indiscriminately to any woody plant that furnishes a convenient hold.

But of the many things that we brush by in this ramble we have not the time to tell, but in this narrow space of moisture between zones of perennial drought, occur ferns of the genera *Pellæa, Notholæna* and *Cheilanthes.* Under the neighboring rocks their prothallia are growing, and young sporophytes of all ages are coming on. Climbing out of the bed of the cañon in a few steps we find ourselves again among the ocotillos and the agaves and the cacti.

Among the shrubby plants none are so important as the guayule, the native name for *Parthenium argentatum.* It is one of the most abundant of all the desert plants, especially on the limestone slopes, and its grayish color gives a distinct character to the landscape where it abounds. A small shrub or dwarf tree, it seldom exceeds four feet in height or a stem diameter of four inches. Its leaves are covered with silvery hairs and its flowers are in inconspicuous heads of composite structure not over one fourth inch across. Its light seeds—one hundred would not fill half an ordinary thimble—are supplied with a papery bract by the aid of which they are driven easily by the wind. Maturing in late summer and autumn, the seeds are dropped to the ground beneath the parent plant, or by some strong gust of wind are borne to a distance, where some find lodgment in a sheltered spot—a crevice of the rock or the cover of some friendly shrub. Here, when the rain comes, it is kept moist for time enough to send down a long, slender, thread-like root before drought again overtakes it. After the fitful showers of summer have passed a long dry season awaits the young plant, so it behooves it to make as much root as possible while the growing conditions are favorable. These slender roots will make a growth of six inches in about a week, before the first true leaf has appeared lifted on the short stem half an inch high, and in six weeks the tap root has been observed fifteen inches long. Thus the plant insures itself against the dry season, and by hardening its stem and leaves, makes still further provision against the vicissitudes that await it.

And this example serves, doubtless, for many other desert plants. We find that the seedlings spring up in abundance under the shelter of bushes and cacti and other perennials. In fact, elsewhere there is almost no chance for the survival of a tender seedling, since the hot sun dissipates so quickly the moisture of even a heavy rain that the surface of the soil is again dry in less than a day. The chances of survival of a seedling are exceedingly remote, and considering the great number of seeds produced and distributed, probably only a very small fraction of one per cent. even germinate.

But interest in this guayule which covers the desert slopes is not alone in relation to its environment, but in the *hule* or gum which it produces, forming no small part of the rubber production of Mex-

ico. Two and a quarter millions of dollars' worth of this product came from one district in one year recently and much more is following. Back in the middle of the eighteenth century it was discovered that the source of the rubber in the balls with which the Indians were wont to amuse themselves, was this guayule. As the Indians formerly did, so one now may extract this rubber in the same crude way by chewing the bark and rejecting the fiber until sufficient gum for the purpose has been accumulated.

That this gum is a by-product in the physiological processes of the plant and stored in its tissues in the form of granules, is not the least of its interesting features, for most of the rubber-bearing plants known to the public are trees yielding a milky fluid from which the rubber is obtained by coagulation. But in this case the rubber is not obtained by tapping, but by the immediate destruction of the plant.

Besides the mesquite and the greasewood and other shrubs that clothe the valleys and lower slopes, the steeper acclivities abound in *Jatropha, Buddleia, Salvia, Bahia, Ephedra* and many other woody plants, members of other genera to the number of a hundred or more, are scattered among the agaves, the palmas and the cacti up and down the mountainside.

One who has not sought these plants where they grow can have little idea of their number and variety, nor of their varied structural and physiological attributes which make for complete fitness in the stern environment of the desert. Here they grow and flourish where it would seem there is no chance for life. But they thrive in these barren wastes—league on league of plain and mountain, where there is neither spring nor pool nor forest shade, blistering heat and glare above and hot dry stones beneath, and find it sufficient.

THE WORLD OF LIFE AS VISUALIZED AND INTERPRETED BY DARWINISM[1]

By ALFRED RUSSEL WALLACE, Esq., O.M., D.C.L., LL.D., F.R.S.

THE lecturer began by stating, that, although the theory of Darwinism is one of the most simple of comprehension in the whole range of science, there is none that is so widely and persistently misunderstood. This is the more remarkable, on account of its being founded upon common and universally admitted facts of nature, more or less familiar to all who take any interest in living things; and this misunderstanding is not confined to the ignorant or unscientific, but prevails among the educated classes, and is even found among eminent students and professors of various departments of biology.

Darwinism is almost entirely based upon these external facts of nature, the close observation and description of which constituted the old-fashioned "naturalists," and it is the specialization in modern science that has led to the misunderstanding referred to. Those who have devoted years to the almost exclusive study of anatomy, physiology or embryology, and that equally large class, who make the lower forms of life (mostly aquatic) the subject of microscopical investigation, are naturally disposed to think that a theory which can dispense with all their work (though often strikingly supported by it), can not be so important and far-reaching as it is found to be.

Numbers, Variety and Intermingling of Life-forms

Coming to the first great group of facts upon which Darwinism rests, the lecturer calls attention to the great number of distinct species both of vegetable and animal life found even in our own very limited and rather impoverished islands, as compared with the more extensive areas. Great Britain possessed somewhat less than 2,000 species of flowering plants while many equal areas on the continent of Europe have twice the number. The whole of Europe contains 9,000 species, and the world 136,000 species already described; but the total number, if the whole earth were as well known as Europe, would be almost certainly more than double that number or about a quarter of a million species. The following table, showing how much more crowded are the species in small than in large areas, was exhibited on the wall. It affords an excellent illustration of the fact of the great intermingling of species, so that large numbers are able to live in close contact with other, usually very distinct, species.

[1] Abstract of a lecture before the Royal Institution of Great Britain.

NUMBERS OF FLOWERING PLANTS[2]

	Square Miles.	Species.
The County of Surrey	760	840
A portion containing	60	660
A portion containing	10	600
A portion containing	1	400

The above figures were given by the late Mr. H. C. Watson, one of our most eminent British botanists, and as he lived most of his life in the country, they are probably the results of his personal observation, and are therefore quite trustworthy.

Continuing the above enquiry to still smaller areas, one perch equalling $\frac{1}{160}$ acre, or less than the $\frac{1}{100000}$ of a square mile, has been found to have about forty distinct species, while on a patch 4 feet by 3 feet in Kent (or about $\frac{1}{25000000}$ of a square mile) Mr. Darwin found twenty species.

The same law of increase of numbers in proportion to areas applies to the animal world, if we count all the species that visit a garden or field during the year, though those that can continuously live there are not perhaps so numerous in very small areas.

THE INCREASE OF PLANTS AND ANIMALS

The powers of increase of plants and animals were next discussed, and were shown to be enormously great. An oak tree may produce some millions of acorns in a good year, but only one of these becomes a tree in several hundred years, to replace the parent. Kerner states that a common weed, *Sisymbrium Sophia,* produces about three quarters of a million of seeds; and if all these grew and multiplied for three years, the plants produced would cover the whole land surface of the globe.

Equally striking is the possible increase in the animal world. Darwin calculated that the slowest breeding of all animals, the elephant, would in 750 years from a single pair produce nineteen millions. Rabbits, which have several litters a year would produce a million from a single pair in four or five years, as they have probably done in Australia, where they have become a national calamity. As illustrative of this part of the subject, the lecturer referred at some length to the cases of the bison and the passenger pigeon in North America, and the lemmings of Scandinavia. In the insect tribes still more rapid powers of increase exist. The common flesh-fly goes through its complete transformations from egg to perfect insect in two weeks; and Linnæus estimated that three of these flies could eat up a dead horse as quickly as a lion.

[2] Other tables illustrating similar facts in other parts of the world were prepared, but not exhibited, as being likely to distract attention from the lecture itself.

It is these enormous powers of rapid increase that have ensured the continuance of the various types of existing life from the earliest geological ages in unbroken succession; while it has also been an important factor in the production of new forms which have successively occupied every vacant station with specially adapted species.

Inheritance and Variation

The vitally important facts of inheritance with variation was next discussed, and their exact nature and universal application pointed out. The laws of the *frequency* and the *amount* of variations, and their occurrence in all the various parts and external organs of the higher animals, was illustrated by a series of diagrams. These showed the actual facts of variation in adult animals of the same sex obtained at the same time and place, which had been carefully measured in numbers varying from twenty to several thousand individuals.

The general result deduced from hundreds of such measurements and comparisons, was, that the individuals of all species varied around a mean value—that the numbers became less and less as we receded from that mean, and that the limit of variation in each direction was soon reached. Thus, when the heights of 2,600 men, taken at random, were measured, those about 5 feet 8 inches in height were found to be far the most numerous. About half the total number had heights between 5 feet 6 inches and 5 feet 10 inches, while only ten reached 6 feet 6 inches, or were so little as 4 feet 10 inches, and at 6 feet 8 inches and 4 feet 8 inches there were only one of each.

The diagrams from the measurements of various species of birds and mammals were shown to agree exactly in general character; and the further fact was exhibited by all of them, that the parts and organs varied more or less independently, so that the wings, tails, toes or bills of birds were often very long, while the body, or some other part was very short, a point of extreme importance, as supplying ample materials for adaptation through natural selection.

The Law of Natural Selection

The next subject discussed was the nature and mode of action of natural selection. It was pointed out that since the glacial epoch no decided change of species had occurred. This showed us that the adaptation of every existing species to its environment was not only special but general. The seasons changed from year to year, but the extremes of change only occurred at long intervals, perhaps of many centuries, with lesser, but still very considerable variations twice or thrice in a century. It was by the action of these seasons of extreme severity at long intervals, whether of arctic winters, or summer droughts, that the very existence of species was endangered;

and it was at such times that the enormous population of most species and their wide range over the whole continents, always secured the preservation of considerable numbers of the best adapted in the most favored localities. Then the rapidity of multiplication came into play, so that in two or three years the population of each species became as great as ever; while, as all the least favorable variations had been destroyed, the species as a whole had become better adapted to its environment than before the almost catastrophic destruction of such a large proportion of them.

It is the fact of the adaptation of almost all existing species to a continually fluctuating environment—fluctuating between periodical extremes of great severity—that has produced an amount of adaptation that in ordinary seasons is superfluously complete. This is shown by the well-known fact that large numbers of adult animals that have not only reached maturity but have also produced offspring and successfully reared them, continue to live and breed for many years in succession, although varying considerably from the mean, while almost the whole of the inexperienced young fall victims to the various causes of destruction that surround them.

The Nature of Adaptation

The next subject discussed was the complex nature of adaptations in many cases, and probably in all; a subject of great extent and difficulty. The lecturer directed special attention to the relations between the superabundance of vegetation in spring and summer, the enormous, but, to us, mostly invisible, hosts of the insect tribes which devour this vegetation, and the great multitudes of our smaller birds whose young are fed almost exclusively on these insects. Without these hosts of insects the birds would soon become extinct; while without the birds, the insects would increase so enormously as to destroy a considerable amount of vegetable life, which would, in its turn, lead to the destruction of much of the insect, and even of the highest animal groups, leaving the world greatly impoverished in its forms of life.

The vast numbers of insects required daily and hourly to feed each brood of young birds was next referred to, and the wonderful adaptation of each kind of parent bird which enables it to discover and to capture a sufficient quantity immediately around its nest, in competition with many others engaged in the same task in every copse and garden, was next pointed out. The facts were shown to involve specialities of structure, agility of motions, and acuteness of the senses, which could only have been attained by the preservation of each successive slight variation of a beneficial character throughout geological time; while the emotions of parental love must also have

been continuously increased, this being the great motive power of the strenuous activity exhibited by these charming little creatures.

Lord Salisbury on Natural Selection

As illustrating the strange and almost incredible misconceptions prevailing as to the mode of action of natural selection, the lecturer quoted the following passage from the late Lord Salisbury's presidential address to the British Association at Oxford in 1894. After describing how the diverse races of domestic animals have been produced by artificial selection, Lord Salisbury continued thus:

> But in natural selection, who is to supply the breeder's place? Unless the crossing is properly arranged the new breed will never come into being. What is to secure that the two individuals of opposite sexes in the primeval forest, who have been both accidentally blessed with the same advantageous variation, shall meet, and transmit by inheritance that variation to their successors? Unless this step is made good the modification will never get a start; and yet there is nothing to ensure that step but pure chance. The law of chance takes the place of the cattle-breeder or the pigeon-fancier. The biologists do well to ask for an immeasurable expanse of time, if the occasional meetings of advantageously varied couples, from age to age, are to provide the pedigree of modifications which unite us to our ancestors, the jelly-fish.

Here we have the extraordinary misconception presented to a scientific audience as actual fact, that advantageous variations occur singly, at long intervals, and remote from each other; each statement being, as is well known, the absolute reverse of what is really the case. It totally ignores the fact, that every abundant species consists of tens or hundreds of millions of individuals, and that as regards any faculty or quality whatever, this vast host may be divided into two portions —the *less* and the *more* adapted—not very unequal in amount. It follows that at any given time, in any given country, the advantageous variations always present are not to be counted by ones and twos, as stated by Lord Salisbury, but by scores of millions; and not in individuals widely apart from each other, but constituting in every locality or country, somewhere about one half of the whole population of the species.

The facts of nature being what they are, it is impossible to imagine any slow change of environment to which the more populous species would not become automatically adjusted under the laws of multiplication, variation and survival of the fittest. Almost every objection that has been made to Darwinism assumes conditions of nature very unlike those which actually exist, and which must, under the same general laws of life, always have existed.

Protective Color and Mimicry

The phenomena of protective coloration and mimicry were very briefly alluded to, both because they are comparatively well known and

had formed the subject of previous lectures; while they are very easily explained on the general principles now set forth. The explanation is the more easy and complete, because of all the characters of living organisms, color is that which varies most, is most distinctive of the different species, and is almost universally utilized for concealment, for warning or for recognition. And further, its useful results are clear and unmistakable, and have never been attempted to be accounted for in detail by any other theory than that of the continuous selection of beneficial variations.

The Dispersal of Seeds

The subject of the dispersal of seeds through the agency of the wind, or of carriage by birds or mammals in a variety of ways, and often by most curious and varied arrangements, of hooks, spines or sticky exudations almost infinitely varied in the different species, was also briefly treated, since they are all readily explicable by the laws of variation and selection, while no other rational explanation of their formation has ever been given.

Conclusion

In concluding, the lecturer called attention to a series of cases which had shown us the actual working of natural selection at the present time. He also explained that these cases were at present few in number, first, because they had not been searched for; but perhaps mainly, because they only occur on a large scale at rather long intervals, when some great and rather rapid modification of the environment is taking place.

In the following paragraph he endeavored to summarize the entire problem and its solution:

> It is only by continually keeping in our minds all the facts of nature which I have endeavored, however imperfectly to set before you, that we can possibly realize and comprehend the great problems presented by the "World of Life"—its persistence in ever-changing but unchecked development throughout the geological ages, the exact adaptations of every species to its actual environment both inorganic and organic, and the exquisite forms of beauty and harmony in flower and fruit, in mammal and bird, in mollusc and in the infinitude of the insect-tribes; all of which have been brought into existence through the unknown but supremely marvelous powers of life, in strict relation to that great law of usefulness, which constitutes the fundamental principle of Darwinism.

MENTAL INHERITANCE[1]

By Dr. MADISON BENTLEY
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OUR chapter of Sigma Xi has recently invited to its membership some two score persons who have shown themselves to be possessed of such talents and aspirations as the society honors and rewards. Of these new members many have finished their preparatory studies, and are entering upon the independent work of science. It is therefore suitable upon this occasion that we should consider some one of those qualities that distinguish the person who is engaged in the scholarly pursuit of knowledge. The quality which I have selected is the possession of temporal or historical perspective; and I propose to use, by way of illustration, the subject of mental inheritance.

Nothing is easier than to exalt beyond its due the present moment. The present is so vivid, so impressive, so intimate, so important for action, as to compel attention; and current means of communication succeed so well in bringing distant lands and deeds within our field of vision that the whole world contributes to the fascination of the passing scene. We all realize this fascination, however much we may set our faces against the vulgar homage paid to the latest mode, the most recent invention, or the last political experiment. We realize it, and, if we are wise, we perceive that the philistine passion for being "up-to-date" (as the street-phrase has it) contains an element of great value—the element of enthusiasm. Scholarly work demands enthusiasm, and every epoch of science has, and, I suppose, will have, its sanctions and its rewards for enthusiastic endeavor. In this regard our own time certainly is not wanting. At a period when the constitution of matter and its elementary forms have, by the discovery of new facts, been brought to the focus of attention; when the development of living forms through their various stages of growth is observed by methods undreamed of by the earlier historians of nature; when the study of evolution has advanced to the stage of analysis and experiment; when the earth is revealing significant traces of primitive man and his works; when psychology proposes new methods for the study of thought and action and for a comparison of the human with the animal mind; when, finally, philosophy rests less upon the authority of great names and systems than upon the immediate data of experience, no ardent novitiate in science can complain that fate has thrown him upon an age of

[1] An address delivered before the Cornell Chapter of Sigma Xi, June 9, 1909.

platitude and dogma, or has denied to him the opportunity of spending his energies in the cultivation of a land of promise.

The kindling enthusiasm of the man of science must not, however, be confused with the philistine's boast that history is a wreck from which only he and his time have been saved. Opportunity which inspires the scholar inflates the time-server and intoxicates the anarchist. The difference between these persons rests at last upon temporal perspective, or the want of it; for it is the apprehension of new opportunities and new needs in the light of old accomplishments that leads to profitable reconstruction of human knowledge. In mechanical invention, the new model may cause the old to be cast upon the rubbish-heap; but in man's interpretation of the world, old theories and old points of view which have served their generation are never discarded; they still mark the stages of human acquisition and take their place in the development of science. Without a knowledge of them, and of their relation to present problems, no man, however ingenious or fertile, should hope to do more than a journeyman's work in the free advancement of learning.

But even when we know the general history of thought and the special histories of our own small divisions of human knowledge, we are apt to overlook the fact that, in a large sense, civilization itself is a matter of the moment, which may be viewed in the light of a broader perspective. Civilization we measure by hundreds and thousands of years. For example, we trace the Mediterranean cultures eight or ten or twelve thousand years, and then we lose the thread; but the whole history of man we reckon in geological epochs. We find his footprints stamped everywhere upon the Quaternary earth, and we find what appear to be vestiges of him in the deeper deposits of the Tertiary. Throughout the brief day of his written history we study him in a long series of related disciplines which we call "the humanities"; while we hand over the unmeasured period of his whole antecedent career to the single science of anthropology. We glance with admiration at his morning work in iron and bronze and brass, his noontime of Athenian culture, his late hours of reflection and invention, and we seek however feebly to illumine the night of his future; but we tend to overlook the antiquity of man, the record of other days and years, and to avoid the question whether civilization is not, after all, still in the experimental stage—whether we ourselves are not next-door neighbors to the barbarian.

When we regard the rapid accumulations of a few thousand years of culture, we realize that civilization lays upon the human mind a staggering load of traditional knowledge and traditional duty. In "Darwinism and Politics" the late Professor Ritchie has defined civilization as "the sum of human contrivances which enable human beings

to advance independently of heredity." Contrast man and other animals. The animal carries over from his parents and from his racial stock the physical equipment and the functional tendencies which enable him to fight the battle of life precisely as his ancestors fought it. If his type varies under natural conditions, it varies so slowly that, as a rule, many generations are required to disclose the change. With man all this is different. As I just now observed, nurture is cumulative. Each succeeding generation takes up its heritage, not where the preceding generation began, but where it left off. Each has to advance by first absorbing the new attainments of its immediate ancestors. In a real sense, therefore, because he has language and books and institutions and traditions, man is

the heir of all the ages.

Notice, however, that man comes into his social heritage only by acquisition during his individual life, by his own individual efforts. Is he, now, as a conscious being, better and better endowed as time goes on for the process of absorption? Does talent grow as knowledge grows? Does mental capacity keep pace with social accumulation? May we not suppose that the men and women of some distant glacial age, who dwelt upon the ice, wore the skin of the seal, and ate raw fish, had as much brain and as generous a measure of talent as have their remote descendents who wear sealskins, and eat ices and caviare? We can not say that they had not. On the contrary, our records, so far as they go, indicate that the social heritage has outstripped the hereditary growth of mind—that, as regards mental endowment, we begin very much as our distant forbears began; only, we proceed at once to burden ourselves with information and obligation which for them did not exist. To compass languages and sciences and histories and arts, and a complicated social and political régime, we are supplied with virtually the same minds that primitive man used for his primitive wants. Is it any wonder, then, that education is the central problem of an advanced civilization?

The question has been raised, however, whether it is not time to look beyond education to the possibility of improving the human stock; whether education is, after all, the only way of civilizing the individual. When the garden vegetable or the domestic animal fails to meet our needs, we improve its breed—so the argument runs; we breed for size, for strength, for flavor, for color, for endurance, for speed, or for general service. When we find that the part of our human stock which is best fitted to carry the cumulative load of civilization is weak, or degenerate, or inclined to sterility, why do we not look to the improvement of those strains that are mentally fittest and to the elimination of the bad? The argument, you observe, assumes that mental endowment and mental capacity are heritable possessions. Is the as-

sumption warranted? We can not say until we have examined the present status of the problem of inheritance; but whether or not we are pessimistic as regards the future of the race, we must agree that the sudden and increasing burden which culture places upon the human mind raises this problem to the first rank of importance.

Suppose that we look, then, at the grounds of belief in the hereditary transmission of mind. The belief itself stands among the fixed convictions of common sense. In our every-day thinking we take it for granted. The child, we maintain, inherits its father's bad temper just as it inherits its mother's good looks. We consider twice before we adopt the foundling, which may be of dull or vicious parentage. We shake our heads over the wayward son, remembering that his father "sowed his wild oats," and we observe "like father like son," or "blood will tell." We expect to find talent in the children of the gifted, thrift or dwarfed intellect or high purpose, according as these qualities are "bred in the bone." The folk-tale of paupered prince or stolen princess who never, though reared as swineherd or scullion, loses regal bearing and courtly demeanor, the wide respect for royal blood, and the easy belief in the "born criminal," alike testify to the common and venerable persuasion that minds, and even morals, are subject to hereditary transmission.

It is only when we stop to inquire precisely *what* is inherited in all these instances, and how it is conceivable that mind should pass from parent to offspring, that we leave the highway of common sense and enter the more difficult path of critical observation and induction. It is obvious that a clear statement of the problem and a forecast of method are of the first importance.

Inasmuch as the notion of "inheritance" involves both the process and the products of transmission, the *inheriting* and the *thing inherited,* a choice of methods is at once suggested. Shall we—that is to say—seek to describe the mechanism of inheritance, or to discover the like qualities that have actually appeared in successive generations of blood-relatives? It is quite impossible to state the alternatives without adverting to the fact that biology has, for a half-century, been absorbed in the parallel investigation of physical inheritance. Nor are we likely to forget, in the midst of our commemoration of Darwin's birth and of "The Origin of Species," that the whole doctrine of organic evolution rests upon the facts of heredity. Whatever the factors that determine racial descent—fluctuating variation, or the sudden change of type, use and disuse, natural, artificial, sexual or organic selection—both continuity in the process of bionomic change and maintenance of the change once produced, demand the conception of a hereditary likeness. Without inheritance the establishment of a stock would be impossible, and without a stock, variations and mutations

would be chaotic and without significance. Thus, ever since Darwin's own attempt at a theory of heredity, we find the students of organic evolution and the breeders of plant and animal races alike devoting themselves to the problems of racial and individual inheritance.

Now it is plainly futile for the psychologist to pretend to first-hand knowledge in a field which is not his own; but, on the other hand, it is equally foolish for him to proceed to the question of mental inheritance without a conception of the methods used, and of the general progress made, by the biological sciences in like inquiries. He must at least bear in mind that the days of pangenesis were followed by the days when Weismann challenged the Lamarckian doctrine of use and disuse, these by the days of rapid development in cytology (the science of the cell and its development), and these days, in turn, by the establishment of the science of genetics and of a revised, if tentative, doctrine of heredity. He must also keep in view the general march of events that led up to the rediscovery of Mendel, the attempt to establish "unit characters" and to segregate the elementary factors in descent, the exploitation of sudden or discontinuous variation at the expense of fluctuation, and the wide use of Quetelet's discovery that individual variation follows the law of probability.

But what, you may ask, has psychology to learn from the doctrine of physical inheritance, when bionomic orthodoxy is overgrown with speculation, when evolutionists themselves are asking, fifty years after Darwin, whether the time is yet ripe for a discussion of the origin of species, when they are raising the doubt whether there has yet fallen from the tree of knowledge the apple that shall suggest the discovery of the universal law of inheritance; when Strassburger affirms that the doctrine of heredity must rest upon the study of the cell, and Bateson replies that the student of evolution is "still, as a rule, quite unable to connect cytological changes with any genetic sequence," and that the direct examination of parent and offspring, not of the germinating cell, is the present key to the problem? What can the psychologist hope to learn about method when the biometrician and the follower of Mendel stand at sword's points; the one fighting for measurements, and schemes of distribution, and coefficients of correlation, and the other for segregation, unit characters and laws of dominance and recession?

My reply is, first, that, in spite of his keen enjoyment of the battle, even the observer from the outside can appreciate the invention and application of clever and useful methods and the advancement of knowledge through conflict; and, secondly, that the student of mental inheritance must get at least half of his equipment from the antecedent studies of biology. To be sure, he finds his material within psychology; but he sees that the strict dependence of mental upon physical derivation calls for an alliance with both the biometrician and the student of physiological genetics.

Let us be more concrete in this matter. If I catch the drift of biological discussion (a hazardous assumption, it may be, for the layman in biology to make), no current and generally accepted doctrine of heredity is able to trace in an unbroken series of structures or events the details of the parental organism through the stages of reproduction to the corresponding details of the offspring. The nuclear and non-nuclear substances that are supposed to represent the "vehicle" of heredity do not, I think (except, perhaps, in a few cases) show variations that represent and correspond to the likeness or difference in given characters as these appear in parent and offspring (*e. g.*, differences in height, in shape of leaf, or in color of hair). If, at some future time, these variations are discovered, then they will, I suppose, represent or correspond to mental as well as physical likeness and difference. At present, however, degree of likeness in blood-relations must be derived from description or measurement of corresponding characters or qualities to be observed in succeeding generations. And the point at which we are here aiming is this: the establishment of inheritance of these qualities, whether physical or mental, must, in principle, rest upon one and the same basis. The inheritance of eye-color and the inheritance of memory-type, the inheritance of an "athletic build" and the inheritance of a bad temper are facts of the same order, and similar methods may be laid under prescription for their establishment.

The great difficulty lies here: how are the characters, mental and physical, to be conceived? and how are they to be described and measured?

We have just seen that upon this question of analysis and measurement, quite apart from the problem of mechanism, the schools of evolution show wide differences of opinion, the biometrician basing his method upon the doctrine of probabilities and proceeding quantitatively, the Mendelian basing his method upon the doctrine of unit characters and segregation and proceeding analytically and by distinction of qualities.

Which of these methods, if either, is psychology to adopt? It happens that psychology has already made a provisional choice; or rather, a choice has been made for her. Biometry has been predominantly concerned with human, Mendelism with non-human, inheritance. It is scarcely an accident, then, that biometrical methods were the first to exploit the mind of man. As you know, biometry's inspiration came from Francis Galton, traveler, explorer, geographer, anthropologist, student of evolution, psychology and sociology. The grandson of Erasmus Darwin, a representative therefore of one of the highly gifted strains of English blood, Galton has devoted himself to a quantitative study of the inheritance of talent and intellect, and to practical measures for purifying and improving the race. His interests revolve

about the central theme of human ability and its dependence upon the stock. In a study of three hundred eminent English families, Galton found the descent of great mental capacity to be far more intensive than in less eminent families; and found, further, that the closer the blood-relationship, the greater was the number of eminent individuals. Later studies, for example, Galton's own recent inquiry into the family history of Fellows of the Royal Society, have likewise shown that the person of superior mind is much more likely than the average to possess superior ancestors and descendants. These facts are justly interpreted as an indication that mental endowment depends in large measure upon direct inheritance.

This kind of inquiry then—the kind that takes human beings in the mass and applies a rough unit of measurement—reveals in a striking way the importance of the hereditary factor in mental ability. However, the method does not constitute a science of heredity. No evolutionist would be satisfied to know that large horses beget large horses, and small horses small horses. It is the degree of likeness of some particular organ, or quality, or function, or peculiarity that the student of heredity now attempts to state, and to state often in numerical terms.

So the present psychological problem of heredity comes back to the question of mental characters and of the best methods for their description and measurement. The psychologist may answer this question in either one of two ways. First, he may fall back upon the distinctions of every-day or popular psychology and say that "a good memory," "sound judgment," "conscientiousness," "affability," "sentimentality" and "industry" are mental characters, and that the way to calculate their heritability is to take a large number of persons, related and not related, estimate the eminence of these qualities in each, note their distribution and derive laws of resemblance. If you find that a good memory, or affability, or industry "runs in families," and is not to be attributed to a common environment, you may conclude that the characteristic in question is heritable. As a matter of fact, this is the method that, for the most part, has been employed within the last ten years; and it has been used either by biometricians themselves, or by the psychologist who has followed their initiative.

Let me cite two or three instances. Professor Karl Pearson, of the University of London, the leader of the biometrical school, collected from teachers data regarding some four thousand children. Color of hair and eyes and cephalic index were among the physical characters graded, and conscientiousness, temper and assertiveness among the mental traits. The degree of likeness between brothers and sisters was found to be substantially the same for physical and mental qualities; in Pearson's terms, each showed a correlation of about 0.5. Again,

Professor Thorndike, of Columbia University, in a study of fifty pairs of twins, by the use of tests and measurements, derived nearly the same degree of correlation (just exceeding .75) for mental and physical characters—a much higher degree of resemblance, by the way, than he found in brothers and sisters *not* twins. The result is noteworthy, even though we may doubt the full validity of the method. The most extensive and painstaking investigation of this order was recently made by two Dutch psychologists, Heymans and Wiersma, of the University of Groningen. Some four hundred physicians responded to a questionary, each giving the results of his intimate acquaintance with a single family. The questions asked pertained to the ardor, impulsiveness, resolution, persistence, generosity, temperance, wit, patience, industry, etc.—about ninety topics in all—of each member of the family selected. The results when thrown into tabular form indicate a high degree of resemblance between parent and child—a higher resemblance between father and son, mother and daughter, than between father and daughter and mother and son. Even after allowance had been made for cultural influences, the degree of likeness was about the same as the inheritance of bodily stature, and the result seems, moreover, to stand in close agreement with Galton's law of ancestral inheritance, which accords to the average parent one quarter the heritage of the offspring.

It is, now, a matter of interest that these studies and others that might be brought under survey suggest that our mental traits and capabilities are derived, very much as are our bodily characteristics, from hereditary endowment. You must, however, have been struck by the grossness of the method of collecting facts. What is the scientific value, you may have asked yourselves, of a teacher's or physician's opinion that *A* is more vivacious or less generous than *B*? Well, the outcome does show, I think, that careful mathematical treatment of extensive data thus collected will yield noteworthy and valuable results. But the more important the results, the greater the demand for refinement of method. Can the method be improved? I think that it can. The biometrician having shown that the problem is capable of solution, let us see if his arch-enemy, the follower of Mendel, can not suggest the improvement in procedure. The improvement that I find suggested is this: the exclusive inheritance of Mendel lays emphasis upon the analysis and separate treatment of individual characters. Now without presuming to decide whether inheritance takes place in all cases, or even as a rule, through the recombination of "unit characters," mental or physical, psychology may profit by the Mendelian principles so far as to insist that inheritance be studied, not in the gross, but in terms of definite and measurable mental structures and functions.

This insistence involves the substitution of a doctrine of mental characters for the popular conception of vague and indefinite traits and peculiarities. How is this doctrine to be derived? Obviously from psychology itself. Neither biometry nor biology nor common sense can furnish the materials.

Look with me for a moment, if you will, to see what psychology has to offer. It is evident that the general psychology of the average normal mind will not suffice when the matter is one of defining *differences* among minds of the same class. Just as physical inheritance must take account of arrays and schemes of distribution, and not of averages, so must mental qualities and magnitudes be arranged with respect to definite individual variations within the class.

A psychology of individual differences is thus invoked; and a psychology of individual differences does exist; or rather, it is in process. The way of scientific description is first to reveal uniformities hidden in the mass, and afterward to seek the rule of variation from the average. General psychology, taken in this sense, is accordingly the older branch of the science—the psychology of what is common to all minds—individual psychology, the newer. So it happens that although the older branch of the science has a well-developed metrical technique, established at almost the same moment that "The Origin of Species" appeared, its quantitative determinations are determinations of psychophysical *constants* and not laws of individual variation. These laws can not then be used (at least not directly) for the statistical study of inheritance. What is needed is a psychology of typical differences, and this it is that individual psychology is by way of supplying. Let me, in a word, indicate its method. It proceeds by experiment to take the dimensions of mind as regards variable functions, *e. g.*, the maximal amount read in a given time and under given conditions, or the number of words remembered or of figures added. The first results show typical differences as between mind and mind. The experimenter next proceeds to factor the performance into elementary processes and functions. By drawing his conditions closer and closer he discovers that the capacity for reading depends upon such simple factors as the range of consciousness, the degree of attention, and the temporal rate of visual processes, factors all capable of measurement and exact description. He discovers that remembrance depends upon the employment of visual or auditory or kinesthetic processes, *i. e.*, that in one observer an eye-mind, in another an ear-mind and in a third a muscle-mind is employed. Of these factors, he can predicate heritability. It is as if "criminality" were reduced to a lack of motor control plus an abnormally intensive passion or lust. "Criminality" would then never be inherited, but the constituent factors might very well be. The method of individual psychology, however, goes farther. After

having reduced a conscious experience to simpler terms, the process of reconstruction begins. The functions and processes that have been reduced to numerical terms are recombined in their several amounts and the integration when complete represents an individual in so far as that individual is typical. With the absolute and exhaustive description of the individual as such, science is not concerned. Typical minds thus derived are, so to say, minds of different length and breadth and thickness. They are analogous to the variable organs and functions of the body. Their scientific description differs from the crude characterizations which we pass upon our friends and enemies as the law of falling bodies differs from an observer's account of a balloonist's accident.

The steps, then, in the procedure of individual psychology are (1) the measurement of a group of mental processes or functions, (2) analysis for the discovery of elementary or fundamental differences, (3) integration of these differential factors, and (4) a classification of types; measurement, analysis, integration, description, a common and justified sequence in the general methodology of science. Compare with this procedure the instances taken a few moments ago from the psychology of common sense—the method employed, let us say, by Pearson. The first and the last steps are combined ("conscientiousness" or "assertiveness" represents the type), analysis and integration are omitted, and an offhand estimate is substituted for careful measurement.

I fear that I have been tedious and that I have perplexed you overmuch with matters remote from your primary interests. My excuse is that I have given you in part a program for the future, and that methods in the making are notoriously self-conscious and awkward of expression. If it were ten years later doubtless I could display more product and vex you less with the process. I could, I have reason to believe, show you this psychological problem of ours, which already at the early stage of crude quantification has proved itself extremely fertile, in a much more mature and fruitful state.

Now that you have before you, in outline, the problem of mental inheritance, its debt to biology, and the present necessity—if the problem is to advance—for the analytical treatment of traits by a science of individual differences, let me in closing return to my earlier remarks touching the import of inheritance in human history. I urged that human knowledge and human obligation have grown out of proportion to human talent. So far as we can tell, the child of to-day possesses the same nervous system, the same sense organs, evinces the same instinctive tendencies, in short, develops with the same physical and mental equipment as the child of unnumbered generations ago. If, so far as education went, the primitive boy was ready for man's estate at

twelve or fifteen, can we wonder that at present the candidate for an advanced university degree has often passed his thirtieth birthday? We should rather marvel at the elasticity of the mind's response to new needs. We know that Quaternary man sometimes possessed artistic ability—perhaps as great ability as the modern European; but what a difference in the product. We can not conceive a medieval musician—to go no further back—producing or comprehending our operas and symphonies; but who would say that native ability in music has grown in the meantime? Are we not then driven to the admission that no principle of selection has for a long time been sufficiently active to raise the level of mental endowment? We live on capital gathered and hoarded by the race. Suppose that we turn spendthrift! Francis Galton reckons that England at its best falls two grades below the highest intellect of Athens; that England produces one man of supreme eminence where the older culture produced two hundred. Suppose that by improving the breed our mental endowment should recover those two grades. The effect, direct and indirect, upon the race is not easily estimated. It is conceivable that it should give to every generation a Homer or a Dante or a Shakespeare, and to each of the European states and America a dozen Newtons and Darwins. Eugenics rests upon a scientific basis and it proposes a well-considered program for future activity. Whatever differences of opinion we may hold regarding the probable success of its methods, we must agree that civilized man may not indolently regard himself as "God's domestic animal"; that he will, on the contrary, do well to examine and to estimate the hereditary factor in his own mental development and to seek to combine for his improvement the conjoint forces of nature and nurture.

ASTRONOMICAL SUPERSTITIONS

By JOHN CANDEE DEAN
INDIANAPOLIS, IND.

THE great majority of our superstitions had their birth in attempts to interpret natural phenomena from erroneous ideas which consist of fancies suggested by the imagination. In other words, most superstitions are attempted short cuts to explain phenomena while omitting natural causation. The average man loves superstition, loves the fictitious, both loves and fears the supernatural and is fascinated by the incomprehensible. From the infancy of the human race men have attempted to explain things according to their external appearances, and whatever was strange or vast, especially if it had visible motion, impressed the beholder with the fear of invisible powers.

During September, 1908, a score of people called the writer by telephone to ask about a brilliant star that had appeared in the eastern morning sky. They had been informed that it was the star of Bethlehem, which appears only once every 300 years. They generally seemed disappointed when told that it was not the star of Bethlehem, but the planet Venus, which instead of becoming visible only once in 300 years, regularly appears twice in a period of 584 days. On attempting to impart further information it soon became evident that their interest was in the *mystery* of the star of Bethlehem and not in any *facts* relating to Venus.

Fashionable society will enthusiastically discuss telepathy, astrology, christian science, psychic force, palmistry, spiritualism, etc., but if one should introduce a subject relating to astronomy or physics, he would be regarded as a pedantic bore. Du Maurier illustrated the indifference of society to science by a drawing in *Punch* entitled "Science and Music at an Evening Party." The scene was in a large London drawing room. In the foreground was a professor earnestly talking to a gentleman, while at the back of the room all the rest of the company were eagerly crowding around a piano. Chesterfield wrote to his son:

> Pocket all your knowledge with your watch and never pull it out in company unless desired; the producing of one unasked, implies that you are weary of the company, and production of the other will make the company weary of you.

While it is true that there is but a small circle of people interested in what is called physical science, yet that science now rules the world and is nearly as despotic as nature herself. Human progress is almost entirely scientific and even our industrial progress is based on applied science.

Even before man essayed to group the stars into constellations he naturally raised the question of the origin, and the manner of the production of the world itself. He then believed it to be flat and immovable, and its seagirt disk supported the sapphire vault above. Gods, men, monsters and heroes familiarly associated and acted their parts, before man had learned to judge by evidence and to place a limit on probability. The sun, the moon and the earth were living beings filled with demons, and sorcery governed belief. Under these conditions there arose no astronomical or geographical difficulties, for where superstition rules evidence becomes useless.

The astronomical ideas of primitive people have been similar the world over. The cosmogony of the Mahometans, as presented in the Koran, is so puerile as to be unworthy of serious consideration. It teaches that the earth is flat and floats in the sea. It is kept in balance by the mountains, and the sky is supported above by a huge dome so perfect that it is impossible to discover a crack in it. Above are the seven heavens, ranged one over the other, the uppermost being the abode of God, which does not rest on the earth, but is supported by winged animals. Meteors are red-hot stones thrown by angels at bad spirits, when they approach too near the seventh heaven. Of the many creation myths, the Jewish story is the one most familiar to us. According to this narrative the universe was miraculously created in six days. The earth is the fixed center enclosed in a great hemisphere called the firmament, which divides the seas above it from those below. More space is devoted to describing the creation of the firmament—now known to be an optical illusion—than to the creation of man himself. The sun, moon and stars were made "to give light upon the earth," and the whole universe was purely anthropocentric, that is, man was the preordained center and aim of all creation. This anthropocentric dogma is closely connected with all three of the great Mediterranean religions, Mosaic, Mohammedan and Christian, hence it has for centuries dominated the beliefs of the greater part of the civilized world.

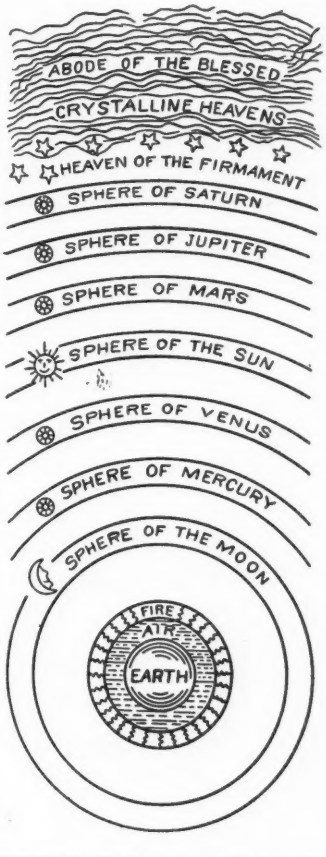
Many of the most charming legends of Greek and Roman mythology were drawn from astronomical subjects. There is no more beautiful illustration of Roman superstition than that shown in Guido's familiar fresco of "Aurora." Why this picture is called Aurora and not Apollo is difficult to explain. The noble sun god is the most important figure of the picture, and he dominates all the rest. He is surrounded by the light tripping Hours, each a very queen of loveliness. Aurora, the goddess of the dawn, leads the throng. From the crown of her beautiful head to the soles of her rosy feet, she is grace incarnate. As she flies she scatters flowers and dew from her hands upon the verdant fields below.

The Roman child was taught that the sun was the actual wheel of Apollo's chariot. In the morning this god arose from the eastern sea

driving his four wonderful horses across the heavens; in the evening he descended into the western sea; at night he slept in a golden boat which was borne along the northern edge of the earth to the rising place in the east. The moon was the abode of the lovely goddess Luna, sister of Apollo, who guided its course in the heavens.

Thus mythology explained astronomical phenomena; the sun, moon, planets, clouds, dawn, and night with its black mantle bespangled with stars, became animated things. The sun, when setting in the brilliant evening clouds, then became Hercules in the fiery pile.

While mythology obstructed scientific progress by finding sacred explanations for every natural event, there were a few gifted, inquisitive minds among the Greeks that sought for knowledge behind the painted curtain of superstition. Thales of the sixth century B.C., was the father of Greek astronomy. He taught that the earth is spherical and that the moon receives her light from the sun. Anaxagoras ascribed eclipses of the moon to natural causes and taught the existence of a creative intelligence. He fell a victim to the superstitions of his age. Sentence of death was passed on him and his family, which required all the eloquence of his friend Pericles to commute to banishment.



ANCIENT THEORY OF THE UNIVERSE

Pythagoras of the fourth century B.C. was a most assiduous enquirer. He is said to have been the first to propose the system of a globular earth and of planets, revolving around the sun. When the Church condemned the theory of Copernicus the indictment was that it was heathenism and Pythagorean.

Modern astronomy may be said to have arisen in the third century B.C., under the patronage of the first king of the Greek dynasty, at Alexandria, Egypt. Euclid, Eratosthenes, Hipparchus and Ptolemy were among the illustrious astronomers of the Alexandrian era. It was in the second century A.D. that Ptolemy published his great work on astronomy called the "Almagest," which during the following four-

teen centuries was universally regarded as a kind of astronomical bible.

One of the curious astronomical superstitions that originated with the Chaldeans, and which persisted almost to our own times, was that of the crystalline spheres. The idea of a spherical universe was a very natural one. It was difficult to see how thousands of bodies could revolve around the earth for generations, without change in their relative positions, unless there was something to retain them in their places. It was believed that the planets and stars were set in a series of concentric orbs or spheres, each so perfectly transparent that bodies in the outer ones were visible through all the intervening ones. The drawing shows the order of the spheres and the system of the universe according to Ptolemy. The earth is in the center enclosed by the sphere of the moon, beyond are the concentric spheres of Mercury, Venus, the sun, Mars, Jupiter and Saturn. Outside of all are the crystalline heavens and the abode of the blessed.

The revolution of the spheres was supposed to produce the most exquisite music which filled all celestial space, but such was its refined quality that it was inaudible to mortal ears. One of the most sublime passages of Shakespeare describes this music:

> Sit, Jessica. Look how the floor of heaven
> Is thick inlaid with patines of bright gold.
> There is not the smallest orb which thou beholdest
> But in his motion like an angel sings,
> Still quiring to the young-eyed cherubims:
> Such harmony is in immortal souls;
> But while this muddy vesture of decay
> Doth grossly close it in, *we* can not hear it.

The following parallel lines are from Milton's "Arcades":

> In deep of night when drowsiness
> Hath lock'd up mortal sense, then listen I
> To the celestial Sirens harmony,
> That sits upon the nine infolded spheres.
> Such sweet compulsion doth in music lie,
> To lull the daughter of Necessity
> And keep unsteady Nature to her law,
> And the low world in measured motion draw
> After the heavenly tune which none can hear
> Of human mould, with gross unpurged ear.

Astronomy has always been the favorite science of the poets. The frame-work of Dante's "Paradise" is constructed on the Ptolemaic system. His ten heavens are arranged in the exact order of those shown in the drawing. The crystal orbs are rotated by angels. He says:

> The virtue and motion of the sacred orbs,
> As mallet by the workman's hand must needs
> By blessed movers be inspired.

It may be said that during the Christian era, up to the thirteenth

century in which Dante lived, there had been no progress in scientific knowledge. He still held to the four elements of the Greeks:

> Thou sayest, the air, the fire I see,
> The earth and water, and all things of them
> Compounded, to corruption turn and soon
> Dissolve.

Although Shakespeare was not born until twenty years after the death of Copernicus, all allusions made by him to the heavens are either astrological or Ptolemaic.

The tendency of a superstition to persist even after closely allied phenomena have been explained on a purely natural basis, is illustrated in the belief that planetary motion was due to "blessed movers." Although Copernicus discovered that the planets revolve around the sun instead of the earth, he still believed that their motion was controlled by guiding spirits. Galileo conclusively confirmed the correctness of the heliocentric theory, but faith in the supernatural motion of the planets was undisturbed. Not until the genius of Newton had discovered and formulated the law of universal gravitation and provided a mathematical foundation for Kepler's laws, were these conducting spirits dismissed. It required the discoveries of three men of genius and two centuries of time to overthrow the foolish superstition of mediocre man.

From the end of the fourth to the beginning of the fifteenth century superstition had given to society a form that prevented the man of genius from being heard. Buckle says that from the sixth to the tenth century there were not in all Europe more than three men who dared to think for themselves, and through fear of punishment even they were obliged to veil their meaning in mystical language. The remaining part of society was sunk in degrading ignorance. Progress became possible only when science essayed to explain observed phenomena by depending on natural causation.

For ages the superstitions of astrology ruled the world by the terror that they inspired. The figure of a man, with entrails exposed, in the front of the family almanac is a survival of Egyptian astrology. Around the figure are the twelve signs of the zodiac with lines extending to the parts of the body supposed to be influenced by the celestial signs. Aries the head, Leo the heart, Capricornus the knees, Pisces the feet, etc. Faith in the influence of the signs of the zodiac remained unshaken in spite of knowledge that the inconstant stars were shifting from one sign to another by the precession of the equinoxes. When the pyramids were built, what is now known as the pole star was so far from the celestial pole that the Egyptians saw it rise and set in the Mediterranean. The Southern Cross was then visible not only in northern Egypt but throughout Europe as far north as London.

Coincidences have ever been mistaken for causes. Owing to the

unparalled brilliancy of the Dog Star, astrologists assigned to it powerful influences, and because it rose just before the sun, at the season when the Nile overflowed, it was supposed to be the mystic cause of the inundation. They gave it the name of Sirius, from the river Nile, which was called Siris in their hieroglyphics. They also called it the Dog Star because, like a faithful watch-dog, it warned them of the approaching overflow, and they waited for its appearance with deep solicitude, for on the overflow of the river depended agricultural prosperity or blighting drought. They computed the length of the year from the heliacal rising of the Dog Star and this is still known as the *Canicular year.* The Romans were equally solicitous and were accustomed to sacrifice a dog to Sirius, to render his influence beneficent to agriculture. Virgil says:

> Parched was the grass, and blighted was the corn:
> Nor 'scaped the beasts; for Sirius from on high,
> With pestilential heat infects the sky.

The time of the year when the Dog Star rose with the sun and appeared to combine its influence with the solar heat they gave the name "dog days" (*dies canicularis*) which began August 4 and ended September 14. Owing to the displacement of the constellations by precession, the time of the heliacal rising of the Dog Star is continually accelerated, hence modern dog days have no connection with this star, and furthermore, recent study of rabies proves that more dogs go mad in winter or early spring than in summer time.

A favorite prediction of astrologers was of cataclysms that would destroy all mankind. Such a catastrophe was foretold to occur in 1186, and a universal deluge was predicted for the year 1542. In the latter year there was to be a conjunction of three planets in the watery sign of the "Fishes." The prophecy was generally believed and the terror was wide-spread. A Noah's ark was built at Toulouse, but the year was distinguished for its drought.

Ridicule is sometimes more efficacious than argument in overthrowing false theories. A skit by Dean Swift discredited astrology, in England, more than all the evidence of science. Swift published a satirical pamphlet under the title of "Predictions for the Year 1708, by Isaac Bickerstaff, Esq.," in which he predicted the death of a well-known astrologer and almanac maker by the name of Partridge. He claimed to have consulted the stars and calculated the exact hour of the astrologer's demise. This was followed by a letter to a man of rank, giving complete particulars of Partridge's death on the day and almost at the very hour foretold. The angry astrologer denounced the pamphleteer, employed a literary friend to write up proofs of his existence and published his almanac for the year 1709. Swift answered all of the arguments, claiming that the denial of death was spurious, and that the deceased was a gentleman who would never have used the

abusive language employed; as for the almanac, everybody knew that almanacs were frequently published under the names of people who had long been dead.

An adequate account of the superstitions of astrology would make a volume, and it would be easy to compile a list of one hundred lunar superstitions that still govern the actions of the uninformed. For example, the new moon if first seen over the right shoulder will bring good luck. If seen over the left shoulder, bad luck. Meat killed when the moon is waning shrinks in the pot. Whatever grows above ground must be planted when the moon is waxing. Whatever grows underground must be planted when the moon is waning. One of the commonest lunar superstitions is that the changes of the moon, at the quarter, affect the weather, and many of our almanacs still publish so-called "Herschel's weather tables," for foretelling changes of the weather, not only throughout all the lunations of the year, but for all future time. We are assured by the almanac makers that the tables are the result of careful consideration of the attractions of the sun and the moon "and so near the truth as to seldom or never fail." Belief in the moon's influence over terrestrial conditions is a mild lunacy by no means wholly confined to the ignorant. A tabulated meteorological record, kept at Greenwich running back for forty years, shows that there are no constant relations between the moon's columns and those recording the readings of the instruments. In other words, lunar meteorological influences are almost inappreciable. Idle fancies are still cherished that the mind and body are affected by the light of the moon, that the rays sometimes produce blindness by shining on the sleeper's eyes, and that death occurs at the time of the changes of tide.

When Copernicus published his work on the "Revolutions of the Heavenly bodies," in 1543, he was already on his deathbed. A few men of learning read it, the doctors of the church rejected it, and it received but little attention until the time of Bruno, Galileo and Kepler, half a century later. During the previous thirteen hundred years the astronomical system of Ptolemy had been regarded with superstitious reverence. It was natural that a geocentric and anthropocentric universe should be drawn, because these errors were conducive to man's interests, pleasing to his extreme egotism, and resulted in the apotheosis of himself. The anthropocentric dogma culminated in the belief that *man* was the preordained center and aim of all creation, while the new heliocentric mechanism of the planetary system relegated both the earth and man to subordinate positions.

In 1610 Galileo ascended the tall campanile of St. Mark's, in Venice, and with his newly devised telescope showed the assembled noblemen and senators that Venus was a crescent, Jupiter the center of a miniature Copernican system, the moon had tall mountains casting dark shadows across her surface, that the star cluster of the Pleiades

contained not seven stars but thirty-six and that the milky way was powdered with stars. In reward for his discoveries the Venetian Senate doubled his salary of professor at Padua, and secured that position to him for life. He was made philosopher extraordinary to the grand-duke of Tuscany, and the next year visited Rome, where he exhibited the wonders of the heavens to the eminent personages of the Pope's court.

But war on Galileo soon flamed forth. The spiritual authorities saw that established dogmas were endangered. He was accused of heresy and atheism. The story of his summons before the inquisition, his trial, conviction and suffering, has been told too often to be repeated here. The triumph of superstition over his astronomical discoveries was for the time complete. This great genius lived to see his works expelled from all the universities of Europe, their publication prohibited, and he knew that he was doomed to face all posterity as one who had committed perjury to escape torture.

Sixteen years previous to Galileo's first summons to Rome, poor Giordano Bruno was burned in that city. In his wanderings to escape persecution Bruno had visited England and while there published his exposition of the Copernican system. Prudence frequently obliged him to change his place of residence and it is not strange that he finally drifted to Venice. Here greater religious liberty was permitted than in other Italian cities, and here the stake had never been erected. It was at the Palazzo Mocenigo, on the Grand Canal, that emissaries of the inquisition finally ran him to earth. The first indictment of the inquisition charged him with teaching that there were innumerable worlds. He was burned to death in the Piazzo Campo di Fiore in the year 1600. Galileo's greatest contemporary was Kepler, who discovered the laws of planetary motion which paved the way to the greater discoveries of Newton. Kepler was abused, imprisoned and warned that he must bring his theories into harmony with the scriptures. Astronomy was then so poorly patronized that to increase his meager income he was obliged to pay homage to the astrological superstitions of Rudolph II. and Wallenstein.

One of Kepler's most terrible experiences arose from the prevailing superstition of sorcery. His aunt and his mother were charged with being witches and sentenced to be burned alive. Through Kepler's indefatigable efforts, and the influence of powerful friends, his mother was saved, but the suffering which she endured during more than a year's imprisonment resulted in her death a few months later. Kepler's aunt was burned at the stake.

The writings of all ages up to the eighteenth century show that comets were believed to be dire messengers of woe. Stars and meteors were generally thought to foretell happy events, especially the birth of heroes and great rulers. Eclipses expressed the distress of nature over terrestrial calamities, while comets portended greater woes than all the

other celestial signs combined. Those who did not recognize them as warnings from God were stigmatized as atheists and Epicureans. John Knox believed them to be tokens of the wrath of heaven, others saw in them warnings to the king to extirpate the Papists. Luther declared them to be the work of the devil and called them harlot stars. Milton says that the comet "from its horrid hair shakes pestilence and war." Whole nations from the king down to the lowest peasant were frequently plunged into the direst alarm by the appearance of these messengers of misery. The comet that appeared the year after the assassination of Cæsar was supposed to be his metamorphosed soul armed with fire and vengeance. It is said that the comet of 1556 had a powerful influence in causing the Emperor Charles V. to abdicate and retire to the monastery of San Yuste. Queen Elizabeth, in 1580, issued an order of prayers to avert God's wrath, and referred to comets, eclipses and heavy falls of snow as evidences of His great displeasure. The periodic comet known as *Halley's* probably caused more consternation than any other within historic times. One of its early appearances was the year of the Norman Conquest and it was supposed to presage the defeat of the Saxons and the death of Harold. At the South Kensington Museum is a copy of the Bayeux Tapestry on which may be seen the comet of 1066. Its return in 1456 spread a wider terror than was ever known before. The belief was general that the judgment day was at hand. People gave up all hope and prepared for their doom. Again in 1607 it alarmed the world by its appearance and the churches filled with terror-stricken multitudes. Kepler, who was then imperial astronomer at Prague, quietly traced its course and discovered that it was outside of the moon's orbit. Tycho had made the same observation respecting a bright comet that appeared thirty years earlier. The announcement of Kepler's discovery caused a great outcry because it attacked the very foundations of the cometary superstitions. It also assailed the dogma of the crystalline spheres, because the motion of a superlunar comet would send it crashing through the spheres. It was hard for superstitious man to give up the "signs of the heavens" that had so long misguided him. As late as the latter part of the seventeenth century a book was published by Father De Angelis, of the Clementine College, Rome, in defense of the old cometary faith. He claimed that comets originate in our atmosphere below the moon. Everything heavenly is eternal. We see the beginning and ending of comets, hence they are not heavenly bodies. They are emanations of dry, fatty matter from the air and may be ignited by sparks from heaven or by lightning. Every one knows that they cause war, pestilence and famine. He had observed a comet at Naples which was so close that its tail almost touched Vesuvius, and it would have destroyed Naples but for the blood of the martyr Januarius.

People were so wedded to ancient errors that it required one hundred years of telescopic work to bring the Copernican system out of

the realms of hypothesis. For generations the universities taught both the geocentric and the heliocentric systems, leaving the student to decide which was right. During more than a thousand years previous to Galileo's discoveries, *superstition* and *unreason* had prevented all human progress. They were the source of untold mischief and suffering and are still man's greatest enemy, while science and reason are his greatest friends. Modern superstitions are often the best comment on ancient astronomical errors.

Newton's astrophysical discoveries placed the solar system on a mechanical basis and dispensed with the planetary guiding angels. Empirical science has since shown that every phenomenon has its mechanical cause, while Darwin's "Descent of Man" has shattered the dogma of anthropocentricism. In the operation of cosmic forces it may now be said that events occur by mechanical necessity regardless of man's interests. During the latter half of the nineteenth century, by the telescopic study of the vast and the microscopic study of the small, a splendid record of accumulated truths was attained. The discoveries of the laws of the indestructibility of force and matter, the unity of nature, the mechanical theory of heat; inorganic and organic evolution and the universality of law, have explained many mysterious phenomena, and forced them out of the darkness of the supernatural to the light of the natural. It has been said that mystery has now been driven from the universe. Belief in the miraculous and the transcendental rests on the assumption that outside and beyond the natural world active forces exist that have no material basis, and of which we can learn nothing by experience, or by any natural means. Such dualistic beliefs are purely idealistic and are evolved from the activity of the brain called emotion. Emotion has nothing to do with the attainment of truth and all doctrines, or opinions, are to be suspected, that are favored by our passions.

Philosophy is the science of which all others are but branches, hence philosophy lies in the province of physical science and not in that of letters. Haeckel says: "All true natural science is philosophy and all true philosophy is natural science." The astronomical errors of the past have arisen from attempts to explain the cosmos out of the inner consciousness, rejecting all scientific methods and substituting faith. While faith may supplement observation in the search for truth, we must not confuse supernatural faith with the natural faith of science. Mark Twain has defined the former as "believing something that you know is not true." The natural faith of science and of practical life is drawn from experience. Kant, Hume, Huxley and Haeckel agree that all knowledge of the reality of phenomena is limited to that revealed to us by experience. Belief must rest on evidence. That belief which is not founded on evidence is both illogical and immoral.

GEOGRAPHIC INFLUENCES IN THE DEVELOPMENT OF OHIO

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OHIO leads the states in its clay products, and its workable clays are practically inexhaustible. Ohio leads also in the number of presidents furnished the union, with unimpaired prospects for the future. Both ratings are consequences of geographic causes, as will appear in later discussion.

This state lies between 38° 27′, and 41° 57′ north latitude; it is bounded by the meridians reading 80° 34′ and 84° 49′. For its width in latitude and its lack of great range in altitude, it has a marked range in mean annual temperature; in southern Ohio the mean annual range is 54°, while in northern Ohio it is 49°; its range in average temperature is about 40°. Lake Erie exerts an appreciable influence on climatic conditions for the northern part of the state.

The Ohio River bounds the state for 436 miles, and the lake shore gives it 230 miles more of natural boundary. About one half of the state line is artificial.

A rock section of the state gives in its lower half a predominance of limestone and shale formations; above this are wide-spread horizons of sandstone and conglomerate. These more resistant formations, belonging to the late Mississippian and early Pennsylvanian periods, are registered in the relief by a mild escarpment or cuesta sweeping to the south and west from the northeastern corner of the state. The northern and western parts consist of shale and limestone formations. There is slight relief particularly in the shale areas. The region of the limestone extends across the western portion of the state coinciding in longer axis with the orientation of the Cincinnati anticline. The drainage pattern resulting from this arching has given the west and southwest part of the state much more relief than would be the case with more horizontal strata.

The general dip of these formations is to the south and east. It is probable that the original consequent streams flowed in this direction. It would be futile, however, at the present time to attempt to sketch the drainage history of Ohio from the Pennsylvanian period, since which time the area has been continuously subject to stream work. Diastrophic movements have introduced some complexity. Several erosion cycles have been inaugurated, but there is evidence that few were

normally terminated. The distribution of the Pennsylvanian formations coincides with the most irregular topography of the state. The average altitude is about 770 feet, and the range in altitude is approximately 1,100 feet.

The present watershed crosses the state from east to west, trending slightly to the south, at an altitude of about 1,100 feet. Drainage lines have divided the upland portion into north-south trending blocks progressively more widely spaced towards the west. These low tracts have been used by the canals and railroads connecting Lake Erie and Ohio River.

The larger part of Ohio is an almost completely severed portion of the Allegheny plateau, extending westward from the northwestern part of Pennsylvania like a great spit into the Mississippi lowlands; the broad valley of the Ohio resembles a bay between this spit and the western slopes of the Appalachians. This somewhat peculiar relationship of topography is the combined result of drainage adjustments due to stratigraphy, and slight diastrophic movements.

Using natural boundary lines, it would be difficult to divide North America into many states. Where such lines do exist, they have not always been utilized. Lake and river, however, form over half the border of Ohio. In general, a water boundary is an asset to a commonwealth; it may be a protection from disputes, and a transit to trade. The reaction varies with other natural boundaries: high altitudes, sometimes barriers, may impose aloofness, or almost complete isolation, whereas water boundaries invite commercial relations.

Geographically Ohio is the back door of the middle and north Atlantic states. This relationship has been of reciprocal value to both areas; as population became more and more dense in the early settlements, and knowledge of the broad lands across the Appalachians spread, a movement in that direction was natural. The easiest route for the more northern of the Atlantic states was through New York via the Mohawk valley, out and along Lake Erie; for the more southern states, through passes in the mountains. Possibly on account of the narrow coastal lands to the south, or possibly because of the greater enterprise there in watching the movements of the French, the southern routes were first explored, and the earliest movements into the Ohio valley came either by way of Pittsburg or by the course of the Cumberland road.

A gross classification of the factors in the development of any region is (1) internal and (2) external. The external include the boundary itself in case the region is a natural one; but geographic situation is frequently very important. When avenues of travel and traffic converge and pass through a state benefit follows. Advantage always comes from proximity to great centers of business or culture

whence energy radiates. Contiguity to activity is an incentive to endeavor. We can scarcely find an area of the earth so void of possibilities as not to experience some stimulation from without. The internal factors in this development are generally obvious. Mineral wealth, energy-producing waterfalls, broad rich fields, varied uplands, a gently blending topography, constant rivers, and a range of climate, make a state self-assertive. Ohio has never been conspicuous for mineral resources: in the early days relative importance might be granted its output of iron ore; the annual production of bituminous coal, while of great advantage to the state, has never been very large, and even now its rank is fourth; natural gas and petroleum have been of much importance to the state, but these resources are always temporary; the supply of clay was great enough even under partial exploitation to stimulate the manufacture of clay products in which the state will be apt to hold a permanent position; in the coarser abrasives, as grindstones and pulpstones, Ohio has always been a foremost producer; with the increasing use of concrete for structural work, greater importance will be given still other natural resources.

But the human responses to natural resources and to geographic environment vary with the people. The same inorganic conditions have elicited a variety of reactions under shifting populations; this variation may after all be the best testimony of geographic influences. Move a people into a different physiography and for some time they will still be the children of their former surroundings. Adaptation is slow, but the law is relentless.

When population becomes too dense for the economic development of a people, the more sturdy among them are the first to emigrate. With few exceptions the earlier settlers in the Ohio area represented the very best colonizing material of the seaboard states. These hardy volunteers in a contest with unbroken lands and unfriendly Indians led to the foundation of one of our most important commonwealths. Among them were not only yeomen, but the enlarged outlook of the land between the lake and the river attracted many of the best schoolmen of the thickly-settled parts. These pioneers not only cherished and perpetuated the place names of New England, but transplanted also the New England zeal for education. In testimony of this spirit among its founders, Ohio possesses more institutions of higher learning than any other state of the union. There was a time in the development of our frontiers when many centers of higher education were needed. Travel was difficult, money was scarce and barter to quite an extent entered into financing these primitive college courses; the colleges and seminaries in Ohio were once even more numerous than now. Advanced standards in education, by a process akin to natural selection, have eliminated many. But the cumulative results of about a century of opportunity for gen-

eral culture must be reckoned among the assets of this state; its dozens of small colleges made it possible for thousands to obtain a training they otherwise would not have received. This inheritance of the better eastern culture, which was stimulated and nurtured by the natural advantages of the region their ancestors were geographically guided into for settlement, accounts for the position won by Ohioans in public life as well as in arts and letters.

The geographical development of any state is usually a complicated problem. Some light, however, is generally thrown on the question by accounting for its particular city that leads all other centers of population. Sometimes the metropolis shifts; if so, a geographic law is always involved. For several decades Ohio was an agricultural community, pure and simple. Wealth increased slowly because there were no ready markets for disposing of products. The first important outlet for farm products came with the introduction of steamboats on the Ohio River in 1810. Naturally the river town that was the most accessible to the agricultural areas became the shipping port. Cincinnati was the earliest clearing house for products that Ohio had to sell. Buying and selling are correlative transactions. A ready market stimulated a desire for things that were counted luxuries in the primitive days, consequently Cincinnati became a manufacturing town, and ever since it has been the leading manufacturing city of Ohio.

Until recent years there has never been any doubt as to which city was the metropolis of Ohio. In the vicinity of what is now Cincinnati a settlement, the second in the state, was made in November, 1788; the next month another handful of men built their cabins on the north bank of the Ohio opposite the mouth of the Licking; this became Cincinnati, whose location assured its growth; on the river, the shipping facilities were considered excellent, and, buttressed by the river flats, the farming lands of the Miami valleys, their development into a city of trade and manufacturing, was speedy and permanent. Before the middle of last century it was stated that:

> The trade of Cincinnati embraces the country from the Ohio to the lake, north and south; and from the Scioto to the Wabash, east and west. The Ohio River line, in Kentucky for fifty miles down, and as far up as the Virginia line, make their purchases here. Its manufactures are sent into the upper and lower Mississippi country.[2]

Cincinnati attained city rank in 1820; during the next decade it became the eighth city in size in the union; from 1830 to 1850 it ranked sixth; by 1880 it had dropped again to eighth place, and at the last census to the tenth place.

The greatness of Cincinnati and the assurance of even marvelous progress in the years to come was prophesied by the editor of the Toledo *Blade*, in 1841:

[2] Henry Howe, "Historical Collections of Ohio," Cincinnati, 1847, p. 221.

I venture the prediction that within one hundred years from this time, Cincinnati will be the greatest city in America; and by the year of our Lord, 2000, the greatest city in the world.[3]

This thought now sounds extravagant, but at that time there was ample reason for feeling sanguine about the future of Cincinnati. No one dreamed that railroads to Baltimore, Philadelphia and New York would in a few years handle the commodities then passing through Cincinnati. Sir Charles Lyell visited this metropolis of Ohio in May, 1842; his explanation of the commercial basis of the city, and its culture is worth repeating:

The pork aristocracy of Cincinnati does not mean those innumerable pigs which walk at large about the streets, as if they owned the town, but a class of rich merchants, who have made their fortunes by killing annually, salting, and exporting, about 200,000 swine. There are, besides these, other wealthy proprietors, who have speculated successfully in land, which often rises rapidly as the population increases. The general civilization and refinement of the citizens is far greater than might have been looked for in a state founded so recently, owing to the great number of families which have come directly from the highly educated part of New England, and have settled there.[4]

However great may be the commercial initiative of frontier peoples, as an asset of the nation their value is largely contingent upon the means of trade and social intercourse. The construction of highways by governments was an old idea in Europe though not widely practised. In this country its advantages to the seaboard states appeared at once upon the drift of population into the trans-Appalachian region. After long agitation the federal government undertook the construction of a roadway westward from Cumberland on the Potomac River; the Chesapeake and Ohio canal later reached this point, and the road became a traffic-feeder to the canal. On the other side of the Ohio River, the government continued this highway across Ohio; this is known as the "national road." Its advantages were obvious, and were duly appreciated. Commodities that had usually passed down the Ohio River were seen on the wharves at Baltimore. News traveled more rapidly along this highway; residents along or near it were envied; the towns it passed through were enlivened; the equipages of aristocracy took this route through the state. Cambridge, Zanesville, Columbus and Springfield each owed something of their rating in that day to the advantages of their location on the national road.

The canal-digging fever struck Ohio shortly after its outbreak in Atlantic states. In 1817 its legislature considered the matter of constructing waterways; the subject came up regularly in the following years, culminating in 1825 in a law that commenced operations. In this same year Clinton's "ditch" tapped Lake Erie. The Ohioans,

[3] J. W. Scott, quoted in Howe's "Historical Collections of Ohio," 1847, p. 221.

[4] "Travels in North America," New York, 1845, Vol. II., p. 61.

therefore, did not wait for proof positive of the advantages of improved waterways. The evidence was forthcoming had it been necessary, for at once after the Erie canal had wedded the lake and the ocean northern Ohio felt a new throb of commercial life. Lake trade was stimulated, harbors were improved, wharves and warehouses constructed; and prices advanced on all commodities that could be conveniently reached. The Ohio legislature had taken the initiative without these evidences. In seven years the Ohio canal, connecting Portsmouth on the river at the mouth of the Scioto with Cleveland on the lake, 306 miles long, was completed. The Miami canal joining Cincinnati and Toledo was commenced in the same year, reached Dayton in 1830,[5] but was not completed to the lake till 1845. Along either canal route trade activity shortly developed the sleepy villages into thrifty towns and cities. Later adjustments have left some of these places only a retrospect; the canal period was their heyday. Others, however, as Newark, Coshocton, Massillon, Akron, Hamilton, Troy and Defiance, have continued to prosper under the conditions incident to the transfer of shipping from the canals to railroads.

The Ohio canal, the course of which was controlled by other considerations than merely joining the river and the lake, makes an ascent of almost 500 feet. Its construction, relative to its length, was much more expensive than the Erie canal which ascends only 445 feet. The maintenance of the Ohio canal also involved greater expense. For this reason, with the extension of railroad lines in the state, we find that by 1856 the canals of Ohio ceased to earn running expenses.[6] During about twenty years, however, these canals were of great commercial importance to the contiguous parts of the state. Even upon the opening of the canal from Dresden to Cleveland the price of wheat advanced from $.25 to $1.00 per bushel.[7]

When we speak of railroads to-day we at once think of one or another of the great through lines. In the early days of railroad construction no one dreamed of even a trans-state road. Until recent years a through line always meant the consolidation of short independently owned segments. Local interest in railroad building in Ohio was lively from the start. Thrifty commercial relations emphasized the inadequacy of boating facilities. The efficiency of the Lake Erie and Erie canal route was not questioned, but there were few canals in Ohio to give access to the lake. The first steam road to operate in the state (1836) had one terminus on the lake at Toledo, the other being at Adrian, Mich. Sandusky had no canal, but by 1839 it com-

[5] *The Ohio Gazetteer*, Columbus, 1839, p. 528.

[6] Poor's "Manual of the Railways of the United States," 1881, p. xvii.

[7] Henry Howe, "Historical Collections of Ohio," Columbus, Vol. II., 1891, p. 325.

pleted several miles of a railroad, "The Mad River and Lake Erie," towards Dayton, which point it reached in 1844. Ohio capital and enthusiasm for railway construction were abundant, as shown by the fact that in 1837 forty-three railroad companies were organized by state charters.[8] Many of these roads were never built, but some of them have become the best lines in the state. By 1846 a road was completed from Cincinnati to Springfield, and by 1848 through steam connection was made between Cincinnati and Sandusky.[9] Columbus and Cleveland were connected in 1851, and during the same year a railroad was finished between Cleveland and Cincinnati.[10] The next year a line was opened from Cleveland to Pittsburg.

Geographically Ohio needed transverse railroads; the lake and the river were its natural thoroughfares to markets; the wide, fertile major valleys of the state trend north-south, and its products move almost by gravity to one outlet or the other. Ohioans, except the immigrant ancestors, never gave further thought to the "Appalachian Barrier"; their commercial friends on the seabooard looked after building the east-west lines.

The rivalry of the Atlantic ports in establishing through railroad transportation to the Mississippi basin was thus an advantage to Ohio. The Hudson-Mohawk valley made the construction of a line a child's task for New York, but the Appalachians imposed on Baltimore and Philadelphia a herculanean undertaking; the former city early recognized the limitations of canals. A citizen of Baltimore in urging the undertaking said:

> Baltimore lies two hundred miles nearer to the navigable waters of the West than New York, and about one hundred miles nearer to them than Philadelphia; to which may be added the important fact, that the easiest and by far the most practicable route through the ridge of mountains, which divides the Atlantic from the western waters, *is along the depression formed by the Potomac in its passage through them.*[11]

In 1828 construction was commenced at Baltimore on a line headed for the Ohio valley, but twenty-five years elapsed before this destination was reached by the Baltimore and Ohio Railroad, the difficulties of construction having been underestimated.

The next year, 1854, the Pennsylvania line reached Pittsburg, with which city Cleveland had been joined the preceding year. In 1852 a road was opened from Buffalo to Cleveland; the same year, one from Toledo to Chicago; and the next year through traffic was made possible

[8] *Ohio Gazetteer*, Columbus, 1839, pp. 531–33.

[9] *Ohio Archeological and Historical Society Publications*, Vol. IX., 1901, p. 190.

[10] *Ibid.*, p. 190.

[11] Philip E. Thomas, quoted in Johns Hopkins University *Studies in Historical and Political Science*, Third Series (1885), p. 99.

from Buffalo to Chicago. In 1857 a road across southern Ohio and on to St. Louis was completed; this was practically a continuation of the Baltimore and Ohio Railroad. By 1860 Ohio had what was considered in that day very ample railway facilities, a condition that contributed largely to the position the state at once took in manufacturing.

Ohio ranks fifth among the states in the gross value of its manufactured products. The state has always been quick in appreciating the demands of its trade environment. Its waterways, natural and artificial, before the period of steam roads, gave it an advantage. No state responded more promptly and effectively to the era of railroad construction. A study of the evolution of railways in this country shows that the network pattern first appeared in Ohio. Manufacturing is invariably stimulated by shipping facilities. Excellent transportation service for decades has been available for producers in this state. Furthermore, the geographic center of population, now in Indiana, has been in and near Ohio for sixty years. Convenience of raw material, accessibility of markets through shipping facilities for finished products, and stability in the supply of labor insured by a normal equilibrium between wages and the cost of reasonable living are essential conditions to a state's maintaining its rank in manufacturing.

The first blast furnace in Ohio was built in 1804 in Mahoning County. The number of furnaces gradually increased throughout the area of the Logan and Pottsville formations which contain the meager iron ore. Limestone is also quite liberally distributed in this same region. Charcoal was used in these furnaces for over two decades, after which coal slowly supplanted wood. Local demands for cooking stoves and other simple necessities stimulated the initial working of these ores. To some extent, the finished product was shipped outside the state. Ohio, ever since these early days, has continued to give an annual output of iron ore, but the supply ceased years ago to be of relative importance.

While fertility of soil insuring a cheap food-supply, and easy topography inviting modern transportation methods, and mobility of labor sustaining manufactories, are of prime importance to industrial growth, nevertheless environment has had much to do in the development of states. The environment here referred to involves the extent to which adjacent commonwealths have either responded to their physiography or have made progress in spite of it. Up to the present time, however, Ohio owes but little of its development to mere geographic situation. But extraneous influences will be of increasing importance in the commercial future of the state. I refer especially to the midway position that Ohio's lake ports occupy in reference to its own and the Appalachian coal fields, and the Superior iron areas. At the present time Ohio stands second only to Pennsylvania in its annual output of steel and

iron products. If physiography is the arbiter, the southern shore of Lake Erie, before many years, will be the center of steel and iron production in this country.[12] The Pennsylvania center of this industry has a momentum and a capital investment that will enable it to stand out long against the logic of geography. Allied with this conservatism are the artificial combinations which tend always to restrain the development of new manufacturing centers. But such commercial egoism will in time recognize the greater advantage in conforming to geographic laws. In reference to a particular nation it is probable that ultimate stability will be reached in the industries concerned largely with the inorganic. After the resources of a country have been thoroughly exploited, equilibrium should come, and be disturbed only by responses made to world-wide influences of commerce. But in this country we are still far from stability in the localization of industries; for example, the center of shoe manufacturing has steadily progressed westward; flour milling left Baltimore for Rochester, and moved later to Minneapolis whence it promises to shift again before many years; slaughtering and meat packing, once centered at Cincinnati, later at Chicago, probably now centers west of the Mississippi.

But an almost equally important factor in the shifting of the steel industry is associated with shipping facilities for the finished products. In this respect, northern Ohio has even now an advantage. With the insured growth of New Orleans as a transfer port for marine cargoes a larger relative proportion of finished steel products will go southward.

The earliest effort in this country to facilitate transportation found expression, as already described, in highway construction. This movement was side-tracked when attention was given to canals and later to railroads. These larger needs, involving the final and longest haul for agricultural products, at least, so monopolized thought that we forgot the first step in the route between the farmer and consumer. Early last century Ohio was given an object lesson in highway construction when the national road from Wheeling, W. Va., crossed the central part of the state. Ohio should have excellent roadways. The state now ranks first in the annual production of road-making limestone. This fact should exert an important influence in the future agricultural progress of the state.

The pasture lands of Ohio have always been important and even at the present time they constitute about one third of the area of the tilled lands. The eastern and southeastern parts of the state, the portion encompassed by the Pennsylvanian formations, contain relatively a larger amount of pasture lands. For several decades Ohio was the

[12] W. M. Gregory, "The Industries of Cleveland, Ohio," *Journal of Geography*, Vol. VI. (1908), pp. 183–87, gives data on the magnitude of the steel industry at this one lake port.

leading state in the production of wool. At the present time it still leads among the states outside of the ranching regions. Its rank is ninth in neat cattle, seventh in swine, and sixth in horses. Associated with its standing in live stock is the corollary fact that in Ohio slaughtering and meat packing is still the fourth industry, while in the whole country it ranks ninth in dairy products, and in the gross value of agricultural products it is third in the union.

The trend of scientific agriculture arising from the work of our colleges and from the federal department of agriculture indicates that there will be greater diversity in products as well as more stability in yield. The present marvelous output of the Mississippi basin is bound to be greatly increased. With the prospect of new markets through shorter hauls made possible by the Panama Canal route, and the improvement of waterways, supplementing the inadequate railroad facilities to New Orleans and other gulf ports, the Ohio River states will be stimulated as never before. The probable diversion of trade from the present great shipping ports on the Atlantic does not necessarily imply shrinkage in their business; it means a compliance with physiographic conditions that naturally divides the output of this great agricultural region, between the gulf and the ocean. A large part of the great interior looks to the gulf; geographically, it is a mediterranean country; such was its geologic origin. Its natural affiliations were aborted when the French were supplanted by the British. The history of commerce, the world over, shows how adjustments are inevitable so long as scientific progress is made in farming and manufacturing, and in transportation itself.

From the standpoint of agriculture, however, still another factor will be conspicuously influential before many years. Immigrants to this country in recent times have largely increased our urban population where employment without capital is found, chiefly in the manufacturing centers. A large percentage of these immigrants are farmers in training, and, as they accumulate money, they gravitate to the country. In the east especially these provident foreigners find no trouble in acquiring land because the natives are glad to get out of the country and into villages or cities, preferring to take their chances on earning as good a living there as they were accustomed to on the farm. The deserted farms in the east do not attest a serious impairment of the soil; they indicate an incapacity on the part of the original farmer to adjust himself to changing conditions in agriculture.

In nearly all parts of Ohio one may find holdings which afforded the original farmers a very doubtful living now yielding a constant profit under the tillage of immigrants. European methods of agriculture combined with ability to reef expenses to the vacillations of income make them successful. During the decade 1890–1900 the average

size of a farm in Ohio was decreased 29.3 + per cent. Particularly in the northern part of the state, throughout the lake-plain belt, specialized and intensive agriculture is now common.

I believe that farming will continue to be one of Ohio's chief sources of wealth. Two thirds of its surface bears glacial soil which contains an abundant and various plant diet. Improved methods of preparing foods for distant markets, and the promise of these markets becoming more accessible through the River-Gulf-Panama Canal route will stimulate cultivation. The advantages of the Ohio River as a means of transportation elicited an early response. In 1794 regular trips, one in four weeks by keel sailboats, were begun between Cincinnati and Pittsburg;[13] this was only six years after the former city was founded. In 1801 a one-hundred-ton vessel for sea trade, built at Marietta, made its first trip down the river, loaded with produce;[14] this was the logical shipping route for the surplus products of southern Ohio.

As early as 1746, six hundred barrels of flour were shipped southward from the Wabash country.[15] French affiliation then dominated the Mississippi valley. The French observed the geography of this interior country in approaching it from either the St. Lawrence or the gulf. New Orleans should be a great port. Logically it is the doorway to nearly half of North America. The aggressive Briton built firmly to the north along the Atlantic; he built so well that it would have been folly to rearrange his structure upon falling heir to the rest of the continent. In extending the commercial structure inland he has not neglected even the slightest natural advantage. But after all, physiographically, the structure is somewhat awkward, and its maintenance expensive. In the organic world, man alone on occasion ignores physiography, but in time he finds it to his highest advantage to comply with the principles of topography. The gulf is the natural outlet of a large part of the Mississippi basin.

[13] Henry Howe, "Historical Collections of Ohio," Cincinnati, 1847, p. 215.
[14] *Ibid.*
[15] B. A. Hinsdale, "The Old Northwest," 1889, p. 50.

THE DECIMAL SYSTEM OF NUMBERS

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IS there a limitation placed upon our thought by the language which we use? Do the Germans take to philosophy more easily than other people because of some peculiarly philosophical bias of their language? These are speculative questions which can never be satisfactorily answered. It may, however, safely be asserted that the literature of a language is immediately dependent upon the written alphabet. It is impossible to conceive of a novel having been written in Babylonian cuneiform characters or in Egyptian hieroglyphics. Romance was the same, in its larger outlines, then as now, but writing was too serious a matter to be undertaken for such fleeting fancies. With a difficult alphabet and lack of facilities for writing, general culture was impossible. The Chinese, in modern times, furnish a striking illustration of the deadening effect of a difficult alphabet.

As literature and general culture are related to the alphabet and written language, so scientific advancement is related to the number system in use and to the system of writing numbers. A slight study of the Roman numerals gives the clue to the reason why the advancement along scientific lines lagged so far behind the general advancement achieved by the Roman peoples. The Greeks had a peculiar genius for arithmetical research, but with them long division was a difficult operation, on account of the symbols. Only an Archimedes could overcome the clumsiness of an unscientific method, and even he could solve but comparatively simple problems.

In order to comprehend the essence of our own number system, it is necessary to distinguish between a number system and a place system. A ten system involves having symbols for 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 groups of objects, respectively, and beyond that separate symbols for the successive powers of 10—100, 1,000, 10,000, 100,000. . . . A five system would involve separate symbols for 1, 2, 3 and 4 groups of objects and further symbols for 5 and for the successive powers of 5—25, 125, 625, 3,125, 15,625. . . . A logically complete 5 system has not been developed among any people of the earth. In fact no other complete system, than a decimal system has ever been developed. Among the Mayas of Central America a 20 system was partially developed. Among the Babylonians there was in use a sixty system interwoven with a decimal system.

A decimal place system involves symbols for 1, 2, 3, 4, 5, 6, 7, 8, 9 and 0. The ideas of 10, 100, 1,000 and successive powers of ten are

involved, but the symbols are given by combination of the symbols for 1 to 9, with the symbol for zero. As our development will show the symbol for nothing was the great stumbling block in the development of a scientific method of writing the numerals. A place system to the base five would require only the addition of a symbol for zero to the symbols for 1, 2, 3 and 4. Leibnitz occupied himself with the binary system, as this required only two characters, one for unity and one for non-entity. To illustrate a binary place system the numbers from 1 to 16 are written, using only 1 and 0.

Three written as 11, means one, two and one unit. Nine written as 1001 represents one cube of two, no squares of two, no first powers of

1	1	$\frac{1}{2}$	.1
2	10		
3	11	$\frac{1}{3}$	.01 repeating
4	100		
5	101	$\frac{1}{4}$	.01
6	110		
7	111	$\frac{1}{5}$	.0011 repeating
8	1,000		
9	1,001		
10	1,010	$\frac{1}{8}$	.001
11	1,011		
12	1,100	Multiply 8×9	
13	1,101	1,000	
14	1,110	1,001	
15	1,111	1,001,000	annex three ciphers.
16	10,000		

two, and one unit. The construction of the arithmetic universe out of the single unit afforded Leibnitz some philosophical satisfaction in connection with his system of monads. All the operations of ordinary arithmetic are possible in this system. We catch a glimpse of our slight comprehension of the infinite totality of numbers in noting that any number that can be expressed with our ordinary ten digits can also be expressed with these two digits, and that even though we used a thousand digits we could add no new numbers. Doubtless it would afford Leibnitz some gratification to know that his binary system is used in modern mathematical analysis in certain delicate proofs. The study of these number systems is not wholly foreign to the history of the decimal system, as traces of the binary and quinary systems appear among primitive peoples.

Among the South Australian tribes the binary system of numeration is almost universal. This is undoubtedly due to the fact that the hands and feet and eyes and ears occur in groups of two in each normal individual. These tribes are not advanced enough to have a system of symbols; such a development would imply a degree of intelligence which would proceed to a higher and more convenient number base. The system is seen in their words; three is given as two and one,

four as two and two, five as two and two and one, and six as two, two, two. This system is found also among South American tribes. The quinary system is the most frequent of all the systems occurring in the numerals of American languages, although the twenty system is common along the Pacific. A study of the words of various American Indian tribes reveals traces of a five system in the formation of the words for six, seven and eight which are given as five and one, five and two, and five and three. The higher numbers, however, are formed on the decimal scale. The word for twenty signifies two tens and the higher tens are similarly constructed. Among some of the African tribes a partial five system is in use. Other tribes of northern Africa have borrowed the decimal notation from their civilized neighbors.

Without a single exception the ancient civilized peoples of all the world—Egyptians, Babylonians, Hebrews, Chinese, Greeks, Romans, Hindus—all used the decimal systems. Such striking uniformity among all the races of the earth requires a natural origin for the decimal number base. As Herodotus first suggested, man counts by tens because he has ten fingers. While there may be logical grounds for the advocates of a duo-decimal system, the ten system is too deep-rooted to be dislodged. Were we to acquire numbers as adults with mature minds, a duo-decimal system might be possible, but with children the acquisition of a twelve system may be said to be almost a psychological impossibility.

Among the Babylonians existed a sixty system mixed with a decimal system. Separate symbols and words are found for 60, 3,600 and 21,600 (60, $\overline{60}^2$, $\overline{60}^3$) and also for 10, 600 and 1,000 and 36,000.

The ingenious hypothesis is advanced by M. Aures that the Babylonians having originally a decimal system, gradually changed from that system of numeration to the duo-decimal and then to the sexagesimal in order to make the number system accord with their systems of measurements. This is the reciprocal movement to that which is taking place with us to-day and that which was effected for France by the French Revolution, the change from duo-decimal and what not else systems of measurements to a decimal system in conformity with our number system. The hypothesis of Aures is justified by the existence of the special symbols and names for 10, 100 and 1,000, and many other curious mixtures of decimal, duo-decimal and sexagesimal systems in the Babylonian measures. There is some comfort to be found in the reflection that ours is not the first civilization to struggle with diverse systems of notation and measurement.

The most striking fact of Babylonian mathematics is that they were in possession of a sixty place system. The famous tablets of Senkereh, discovered by the English geologist, W. K. Loftus, give tables of square and cubic numbers in cuneiform characters. In these tables the numbers proceed regularly up to 8^2, which is given as 1.4, 9^2 is given as

1.21, $\overline{10}^2$ as 1.36, $\overline{20}^2$ as 6.40—naturally all in cuneiform characters. The only possible interpretation of this is that the 1 in the left hand place stands for 60. The table of cubic numbers bears out this interpretation as $\overline{30}^3 = 27{,}000$ is given as 7.30, meaning $7 \times 3{,}600$ or $7 \times \overline{60}^2 + 30 \times 60 = 25{,}200 + 1{,}800$ which makes the total of 27,000. Up to date no documents have been found which show the presence of the zero in this system. Even though a zero, and with it thus a full place system, had existed the unwieldiness of the large base would have operated against a universal adoption of the system; a number system must be adapted to child mind.

Our division of the day into 24 hours is probably a heritage from the Babylonians; the division of the hour and minute into sixty parts is certainly a survival from this hoary system. So also the division of the arc of the circle into 360° and the further subdivisions have come to us from this extinct civilization. Greek astronomers and through them all European astronomers borrowed much from the same source, and for over fifteen hundred years of the Christian era sexagesimal fractions were used in all arithmetical computation. The first tables of trigonometric functions were on the basis of a radius of 600,000, later 6,000,000, finally to be discarded by Regiomontanus in 1470 for the base 10^5, later for 10^{15}, and then by the great Vieta, in 1579, for the base one with decimal values.

It is entirely within the bounds of possibility that the first development of the Hindu, commonly called Arabic, place system was due to some oriental scholar who was familiar with the writings of these ancient Babylonians. Abundant testimony exists tending to prove the communication between Europe and the east. Having special symbols, such as existed in India for 1, 2, 3, 4, 5, 6, 7, 8 and 9 as early as the second century, acquaintance with this advancement of the Babylonians may have suggested the step to a decimal place system and the innovation of a zero. The existence of a Babylonian zero symbol would strengthen this hypothesis; even a blank space may have been the first symbol.

The Egyptians were in possession of a complete decimal system, with separate symbols for 1, 10, 100, 1,000, 10,000 and higher powers of 10. The famous Papyrus Rhind of the British Museum gives us a practically complete Egyptian arithmetic. The striking peculiarity of their arithmetic consisted in the work in fractions which was confined almost entirely to unit fractions. The Ahmes Papyrus of date about 1700 B.C. gives a table for a conversion of fractions from $\frac{2}{3}$ to $\frac{2}{99}$ into unit fractions. The tremendous inertia of even the clumsiest system once established is seen in the fact that Greek manuscripts of date 700 A.D., at least 2,200 years later, contain this same bungling system of fractions. Aside from this malign influence European arithmetic was not affected by the Egyptian.

Among the ancient Semitic peoples we find separate symbols for 1, 10, 20 and 100. Noteworthy is the use of twenty in forming the higher powers of ten; sixty is written as three twenties. The use of twenty as a unit of higher order goes back to primitive counting on fingers and toes, which operation still exists among Pacific coast tribes of Indians, Mexicans and Esquimaux. Persistence of the unit twenty is seen in our word for score; more markedly in the French quatre-vingt for 80.0.

Some time before the Christian era, the Phœnicians changed to an alphabet system of numbers. The first nine letters of their alphabet were given the number values 1 to 9; to the second nine attach the values 10—90; and similarly with the hundreds. From the Phœnicians this method was taken by the Hebrews and the Greeks. In any numerical work the order hundreds, tens, units is strictly observed. Nevertheless, as to each word there was a definite number value the Hebrews indulged in secret writing by giving one name with the hint to the wise to substitute some other well-known name with the same number value. This near-punning occurs in the Book of the Revelations, "the number of the Beast is 666," referring to the Roman Emperor whose name written in Hebrew letters had the numerical value, 666.

A different type is presented by the Attic system of numbers in use among the ancient Greeks, in which the symbols are the first letters of the corresponding Greek words.

$1 = \mathrm{I}$.
$5 = \Pi$ or Γ from πέντε for five.
$10 = \Delta$ from δέκα for ten.
$100 = \mathrm{H}$ from ἑκατον for hundred.
$1{,}000 = \mathrm{X}$ from χίλιοι for one thousand.
$10{,}000 = \mathrm{M}$ from μυρίοι for ten-thousand.

Combinations Γ^{Δ}, Γ^{H}, Γ^{X}, Γ^{M} were used for 50, 500, 5,000 and 50,000. The advantage in numerical computation of this system over the alphabet system is great as the connection between 50, 500 and 5,000 is brought out by the symbols. Deceived by the apparent simplicity of the alphabet system, the Greeks abandoned the Attic in favor of the alphabet form.

$$\gamma + \delta = \zeta, \qquad 3 + 4 = 7,$$
$$\lambda + \mu = o, \qquad 30 + 40 = 70,$$
$$\tau + \upsilon = \psi, \qquad 300 + 400 = 700,$$

are apparently simple, but they fail to show any trace of the underlying decimal system.

$$\mathrm{III} + \mathrm{IIII} = \Gamma\Pi. \qquad 3 + 4 = 7.$$
$$\Delta\Delta\Delta + \Delta\Delta\Delta\Delta = \Gamma^{\Delta}\Delta\Delta. \qquad 30 + 40 = 70.$$
$$\mathrm{HHH} + \mathrm{HHHH} = \Gamma^{\mathrm{H}}\mathrm{HH}. \qquad 300 + 400 = 700.$$

These second forms are organically connected, whereas the first forms exhibit no connection.

During the first thousand years of the Christian era, the alphabet system held full sway; then for a period of nearly five hundred years the Roman and the Greek systems vied with each other for popular favor among European arithmeticians.

The origin of the Roman numerals is lost in obscurity. Undoubtedly the symbols are from Etruscan sources changed gradually into the similar Roman letters. It is to be noted that such changes in the forms of letters were most easily effected by copyists previous to the invention of printing. Just as the Babylonians operated with the common denominator sixty, so the Romans confined themselves to the denominator 12 (and powers of 12). The twelfth represented at first a definite concrete unit of weight or length, the uncius, which later acquired a numerical sense.

LIST OF ROMAN 12THS

Name	Value	Symbol
as	1	I
bes	$\frac{8}{12}$	S=
semis	$\frac{6}{12}$	S
quadrans	$\frac{3}{12}$	=—
uncia	$\frac{1}{12}$	—
sextula	$\frac{1}{72}$	—

There were further names and symbols for $\frac{11}{12}$, $\frac{10}{12}$, $\frac{9}{12}$ or $\frac{3}{4}$, $\frac{7}{12}$, $\frac{5}{12}$, $\frac{4}{12}$ or $\frac{1}{3}$, $\frac{2}{12}$ or $\frac{1}{6}$, $\frac{1}{12}$, $\frac{1}{24}$, $\frac{1}{36}$, $\frac{1}{48}$, $\frac{1}{144}$, $\frac{1}{288}$. These were used to apply to any measurements.

The connection between the unciæ and our inches and ounces is evident.

The Roman numerals like their prototypes in the Attic system of Greece and the more ancient semitic systems, left no traces upon our current arithmetic. However, the Roman system of calculating upon a reckoning table was one of the vital factors in the development of the decimal place system. This system was not peculiarly Roman, as ancient Greek reckoning tables are found in several continental museums. The Chinese suan-pan, in popular use in Chinese laundries, is familiar to most readers. A similar instrument is found in Russian elementary schools.

A series of parallel grooved spaces and a goodly number of pebbles constitute the simplest form of one of these primitive calculating machines. Any right-hand column is chosen as the units column and the successive columns to the left are designated by the symbols for the successive powers of ten. Ten pebbles in any one column are replaced by one pebble in the next column to the left. Addition and subtraction are simple operations and even multiplication with small integers is not a difficult operation. Division was an accomplishment which only masters achieved; the complicated rules given by some medieval writers on the subject lead one to suspect that the writers were concealing ignorance in obscurity. On the Roman abacus the extreme right-hand column represented twelfths (unciæ) and three smaller columns

denoted 24ths, 48ths and 36ths respectively. On the Greek abacus also the right-hand columns were of mixed systems which serve to make the calculating more difficult.

A late development of the same nature was the reckoning on lines which continued into the sixteenth century. The essentials are similar.

A glance at the accompanying diagram explains the connection between this system and the decimal place system. The upper part represents the number 4,063, the lower part the number 3,251. It seems such a slight step, after acquiring special symbols for the groups of one

M	C	X	I
0		0	0
0		0	0
0		0	0
0		0	
		0	
		0	
		0	
0		0	
0	0	0	
0	0	0	0

to nine to construct a symbol to indicate a blank space, but that step took centuries to achieve.

Of all ancient peoples the Hindus occupied themselves most deeply with numbers. To some of their scholars came the conception of a connection between the infinite of the universe and the infinite of numbers. This longing for the infinite found expression in the construction of ever increasing numbers. Buddha calculates the number of grains of sand in a mile and shows how to compute the number in a sphere whose radius is the distance to one of the fixed stars. Not content with this, the Buddha goes on to show how even greater numbers may be expressed, arriving at the equivalent in modern exponential notation of $10^{(7+9.46)} = 10^{421}$. The numerals of the ancient Tamils, who, like the mountaineers of Appalachian America, conserve the traditions of a more remote civilization, show us that the Hindu peoples originally had special symbols not only for the first nine units, but also for the nine tens, the nine hundreds and even the nine thousands. The formation of the sequences of large numbers revealed the futility of having separate signs for the mixed tens and hundreds, with the consequent result that they dropped the separate symbols for 20 to 90, 200 to 900, and used the pure decimal units in connection with the symbols for one to nine. A similar development took place in quite early times —pre-Christian—among the Chinese but their clumsy notation obscured the realization of the possibility of a simpler place system.

The reading of a large number in Hindu style reveals how close their nomenclature brought them to the place system.

In modern notation, 8,443,682,155, 8 billion, 443 million, 682 thousand, 155.

In Hindu, 8 padmas, 4 vyarbondas, 4 kôtis, 3 prayoutas, 6 lakchas, 8 ayoutas, 2 sahasra, 1 çata 5 daçan 5.

In Arabic and in later German, eight thousand thousand thousand and four hundred thousand thousand and forty-three thousand thousand and six hundred thousand and eighty-two thousand and one hundred fifty-five.

In Greek, eighty-four myriads of myriads and four thousand three hundred sixty-eight myriads and two thousand one hundred fifty-five.

It is well established that in different parts of India the names for some of the higher powers took different forms, even the order was interchanged. However, as the significance of the name was further given by the order in reading, the variations did not lead to error. Indeed, the variation itself may have necessitated the introduction of a word to signify a vacant place or a lacking unit, with the ultimate introduction of a zero symbol for the word. The use of a special word to indicate absence of a unit is not hypothesis, but is found in verses in the ancient Indian book on astronomy, the Sourya-Siddhanta, and in numerous other ancient Hindu writings.

Brockhaus has well said that if there was any invention for which the Hindus by all their philosophy and religion were well fitted it was the invention of a symbol for zero. This making of nothingness the crux of a tremendous achievement was a step in complete harmony with the genius of the Hindu. The exact date of the birth of the zero symbol is not known, doubtless never will be known. The burden of proof points to a use of this symbol towards the beginning of the fifth century of our era. Wide-spread use in India did not occur until towards the ninth century. With nations as with individuals, the complete significance of great idea is not achieved in a moment; even as this idea itself in its unfolding required the labor of master minds of many centuries, so the appreciation and application of this advance required centuries for its completion.

The intellectual awakening of the Arabs beginning about the middle of the eighth century, manifested itself in the appearance of numerous translations of Greek, Syrian and Hindu works. Barbarians as they undoubtedly were at the period of their first conquests, the Arabs distinguished themselves by their desire for the further conquests of the science and literature of the subjugated peoples. The Persian invasion brought them close to the civilization of the Hindus and here the scholars went further than the flag. Hindu astronomy and astrology accompanied by the Hindu arithmetic were given to the scientific public in translations made at the command of one of the first great Mahome-

tan patrons of learning, the Caliph Almansur, who reigned during the second half of the eighth century.

For a period of five hundred years the intellectual activity of the Mediterranean countries was well nigh confined to the Arabs. With what extraordinary diligence the pursuit of foreign learning was made by these erstwhile wanderers is evidenced by the thousands upon thousands of Arabic manuscripts. The library of Hakam at Cordova in Spain contained 400,000 manuscripts; the catalogue alone is in 44 volumes. Original work in science and mathematics did not come from Arabic hands, but the debt of civilization is none the less great as they were long the conservors of the learning of the Greeks and Hindus. The revival of Euclid was brought about by translations made from the Arabic; indeed many important Greek works in all the sciences have come to us only from Arabic sources.

The points of contact of Europeans and the Ottomans were numerous. From Asia Minor at the east to Greece was a well-traveled route; Sicily, Sardinia and Africa were in constant communication with Italy. Moorish Spain was for centuries a meeting place of English, French, Polish and German scholars.

The church played an important rôle in the spread of the Hindu numerals over Europe, and at the beginning of the thirteenth century in England, France, Germany, Italy and Poland, the arithmetic of the far east was explained by churchmen who had learned of Moorish teachers. However, it remained for a commercial traveler (line he handled is not known) to write the epoch-making work explaining the new doctrine. Leonard of Pisa traveled for business purposes in Africa, Syria, Egypt, Greece and Sicily and incidentally he acquired enough mathematics to make him the greatest mathematician since Archimedes. His Liber Abaci, or book of the abacus, first edition written in 1202, gave the first masterful exposition of the better way to reckon. It was for four centuries the great work of reference in this field.

With the knowledge of the Hindu method spread over all Europe at the beginning of the thirteenth century the acceptance of the improvement might be presupposed, but as late as 1520 arithmetics were published entirely in Roman numerals. The logically self-evident step to the right, to decimal fractions, required further centuries for its completion. The step up, to exponents to base ten, was made rather quickly, but has not yet taken its proper place in commercial work.

It is not too much to say that the present development of modern science would be impossible without our number system, yet how slow the world was to accept the reform. Is not the same story being repeated in the United States and England with the decimal system of weights and measures? But the optimistic soul regards chiefly the final acceptance with the comfortable assurance that the forward movement is as sure as it is slow.

THE ARGUMENT FOR ORGANIC EVOLUTION BEFORE "THE ORIGIN OF SPECIES"

By Professor ARTHUR O. LOVEJOY
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I

IN this year of the Darwin centenary it is worth while to raise two questions which have, in the mass of literature elicited by the occasion, received less consideration than they merit. At what date can the evidence in favor of the theory of organic evolution—as distinct from the hypothesis of natural selection—be said to have been fairly complete: in other words, how early were the facts and principles from which the truth of that theory is now ordinarily inferred sufficiently known to all competent men of science, to require the inference, even though it was not, in fact, generally made? And by what English writer was a logically cogent argument for the theory first brought together and put before the public? The interest attaching to these questions is much more than merely historical. The answer to them will afford a sort of object-lesson in the logic of scientific reasoning. Here is a doctrine now accepted by all naturalists: at what point, in the century-long accumulation, through half a dozen separate sciences, of the evidences inclining to that doctrine, ought we to say that the balance of logical probability turned decisively in its favor? The inquiry will also be found, I think, to throw a somewhat instructive light upon the psychology of belief, and to show how far, even in the minds of acute and professedly unprejudiced men of science, the emotion of conviction may lag behind the presentation of proof.

By this time, no doubt—though it has not long been so—every schoolboy knows that Darwin did not invent the theory of evolution. The Darwin centenary itself has served to remind the public of the names and works of at least some of the earlier protagonists of the doctrine: of the elder Darwin, namely, of Lamarck, of Geoffroy St. Hilaire, of the author of the "Vestiges of the Natural History of Creation," and of Herbert Spencer. It is less commonly remembered, but perhaps not universally forgotten, that among English-speaking naturalists, the theory was a commonplace topic of discussion for two or three decades before 1859, and especially after the publication and immense circulation of the successive editions of Robert Chambers's "Vestiges," of which the first appeared in 1844. Geological text-books of the period referred to the "theory of transmutation of species" as

a matter of course, though usually only to reject it as an exploded hypothesis. Thus the "Elements of Geology," of Alonzo Gray and C. B. Adams, 1852, enumerates three theories which have been advanced respecting the origin of animal species: (1) Successive special creations; (2) "transmutation, which supposes that beings of the most simple organization having somehow come into existence, the more complex and the higher orders of animals have originated in them by a gradual increase in the complexity of their structures";[1] (3) *generatio æquivoca* of individuals and species. The first is adopted, but the second is discussed at greatest length; on it the authors remark that "those who have adopted the theory of transmutation have generally detached it from Lamarck's theory of appetency, and not attempted to explain *how* the process of transmutation goes on." The argument for evolution is similarly discussed and "refuted" in "Geological Science," a popular text-book by D. T. Ansted, F.R.S., 1854. To this refutation, indeed, the greatest of English geologists had devoted three chapters of his "Principles of Geology"[2] before 1835.

But though such facts as these are, as I have said, now fairly familiar, the notion still widely prevails, even among biologists, that no serious *proof* of evolution either existed or had been published before the appearance of the "Origin of Species"—or at all events, before the late 1850's.[3] Professor Joseph Le Conte, indeed, in his "Evolution and Its Relation to Religious Thought,"[4] made it a reproach against both Lamarck and Chambers that they had unscientifically embraced the hypothesis before the evidence for it was ripe; and considered it fortunate for science that their notions died still-born, under the weight of the great authority of Cuvier and Agassiz. "I know," wrote Le Conte, "that many think with Haeckel that biology was kept back half a century by the baleful influence of Agassiz and Cuvier; but I can not think so. The hypothesis was contrary to the facts of science, *as then known and understood.* It was conceived in the spirit of baseless speculation, rather than of cautious induction; of skilful elabora-

[1] I quote from the reprint of 1854, p. 87.

[2] The writer's copy of Lyell's "Principles" is the first American from the fifth London edition, 1837.

[3] This opinion has, for example, been expressed by Poulton in his "Charles Darwin and the Theory of Natural Selection." "The paramount importance of Darwin's contributions to the evidences of organic evolution are [*sic*] often forgotten in the brilliant theory which he believed to supply the motive cause of descent with modification. Organic evolution had been held to be true by certain thinkers during many centuries; but not only were its adherents entirely without a sufficient motive cause, but their evidences of the process itself were erroneous or extremely scanty. It was Darwin who first brought together a great body of scientific evidence which placed the process of evolution beyond dispute, whatever the causes of evolution may have been" (p. 100).

[4] Second edition, 1905, pp. 33–35.

tion, rather than of earnest truth-seeking. Its general acceptance would have debauched the true spirit of science. . . . The ground must first be cleared . . . and an insuperable obstacle to hearty rational acceptance must first be removed, and an inductive basis laid." This last, Le Conte goes on to argue, was largely the work of Agassiz, opponent of evolutionism though he was. Now, it is, of course, undeniable that the premature adoption of a hypothesis is a sin against the scientific spirit, and that the chance acceptance by some enthusiast of a truth in which, at the time, he has no sound reason for believing, by no means entitles him to any place of honor in the history of science. But what constitutes prematurity in this particular matter? And *was* the evolutionary hypothesis "contrary to the facts of science, as known and understood" at any time after 1840?

The prevalent belief that it was is chiefly due to two things. The first is the fact that before 1859 few English naturalists of high standing accepted, and almost none publicly avowed, the theory of descent; whereas, after the publication of the "Origin," such notable names as Huxley, Lyell, Hooker and Asa Gray were speedily numbered among the disciples of the doctrine, and in the ensuing five years it was well upon its way towards its eventual complete triumph. The other source of the supposition that Darwin presented the first adequate grounds for believing in evolution is the express testimony of Huxley, whose paper on the reception of the "Origin of Species"[5] has come to be the principal source of information on its subject. In that article, and in several letters and other writings, Huxley takes credit to himself for his rejection of the transformation-theory until he became acquainted with Darwin's work; and he never expressed any sentiment far short of contempt for Chambers's "Vestiges." He wrote in 1887:

> I must have read the "Vestiges" . . . before 1846; but if I did, the book made very little impression on me, and I was not brought into serious contact with the "species" question until after 1850. . . . It seemed to me then, as now, that "creation," in the ordinary sense of the word, is perfectly conceivable. . . . I had not then, and have not now, the smallest *a priori* objection to raise to the account of the creation of plants and animals given in "Paradise Lost." . . . Far be it from me to say that it is untrue because it is impossible. I confine myself to what must be regarded as a modest and reasonable request—for some particle of evidence that the existing species of animals and plants did originate in that way, as a condition of my belief in a statement which appears to me highly improbable. And, by way of being perfectly fair, I had exactly the same answer to give to the evolutionists of 1851–58. . . . The only person known to me whose knowledge and capacity compelled respect, and who was, at the same time, a thorough-going evolutionist, was Mr. Herbert Spencer. . . . But even my friend's rare dialectic skill and copiousness of apt illustration could not drive me from my agnostic position. I took my stand upon two grounds: Firstly, that at the time the evidence in favor of transmutation was wholly insufficient; secondly, that no suggestion respecting the causes of the

[5] Published as Ch. XIV. of "The Life and Letters of Charles Darwin."

transmutation assumed, which had been made, was in any way adequate to explain the phenomena. Looking back at the state of knowledge at the time, I really do not see that any other conclusion was justifiable. . . . As for the "Vestiges," I confess the book simply irritated me by the prodigious ignorance and thoroughly unscientific habit of mind manifested by the writer. If it had any influence at all, it set me against evolution. . . . Thus, looking back into the past, it seems to me that my own position of critical expectancy was just and reasonable. . . . So I took refuge in that *tätige Skepsis* which Goethe has so well defined; and, reversing the apostolic precept to be all things to all men, I usually defended the tenability of received doctrines, when I had to do with the transmutationists; and stood up for the possibility of transmutation, among the orthodox.

In this matter Huxley is assuredly a witness whose testimony should not lightly be set aside; for to his attainments as a naturalist he ordinarily joined singular logical acumen and rare openness of mind. Yet I think it possible to show that the passage just quoted gives a thoroughly misleading view of the logical status of the argument for evolution, as it existed in the light of the science of the period; that the attitude which Huxley assumed from 1850 to 1858 was contrary to all sound ideas of scientific method; and that he does the reputations of both Spencer and Chambers serious injustice. I shall attempt to establish these conclusions mainly by showing that the arguments and facts chiefly relied upon by Huxley himself and other early champions of transformism were entirely familiar and well authenticated from fifteen to twenty years before 1859, and had virtually all been clearly noted and pertinently used in the published evolutionary reasonings of Chambers or of Spencer. The truth is—as the evidence to be adduced will make clear—that Huxley's strongly emotional and highly pugnacious nature was held back by certain wholly non-logical influences from accepting an hypothesis for which the evidence was practically as potent for over a decade before he accepted it as it was at the time of his conversion. These influences did not in Huxley's case, as they did in so many others, proceed from religious tradition or temperamental conservatism. But Huxley had unquestionably been strongly repelled by the "Vestiges." The book was written in a somewhat exuberant and rhetorical style; with all its religious heterodoxy, it was characterized by a certain pious and edifying tone, and was given to abrupt transitions from scientific reasoning to mystical sentiment; it contained numerous blunders in matters of biological and geological detail; and its author inclined to believe, on the basis of some rather absurd experimental evidence, in the possibility of spontaneous generation. All these things were offensive to the professional standards of an enthusiastic young naturalist, scrupulous about the rigor of the game, intolerant of vagueness and of any mixture of the romantic imagination with scientific inquiry, a little the victim, perhaps, of the current scientific cant about "Baconian induction," and quite incapable of

taking, towards any doctrine or movement, any attitude intermediate between contemptuous hostility and ardent partizanship. Full advantage, moreover, had been taken, by the eminent scientists who were also champions of religious orthodoxy, of the faults of Chambers's book; they contrived very successfully to put about the impression that to be a "Vestigiarian" was to be "unscientific" and sentimental and absurd. These were three qualities which Huxley would have been peculiarly averse to being charged with. Finally, he seems to have been exasperated most of all by a single loose piece of phraseology that now and then recurs in the "Vestiges." Chambers, namely, was prone to speak of "laws" as if they were causes and, more particularly, as if they were secondary causes to which the "Divine Will" delegated its agency and control. To Huxley, from the beginning of his career, this hypostatizing fashion of referring to "laws of nature" was a *bête noire;* and in 1887 we still find him pursuing the author of the "Vestiges" with ridicule because of his "pseudo-scientific realism."[6] He, therefore,[7] in 1854, almost outdid the *Edinburgh Review* in the ferocity of his onslaught upon the layman who had ventured to put forward sweeping generalizations upon biological questions while

[6] "Science and Pseudo-science," 1887. Huxley's criticisms are curiously beside the mark. He argues that, whether you suppose that the Creator operates uniformly but directly "according to such rules as he thinks fit to lay down for himself," or that "he made the cosmical machine and then left it to itself," in either case his "personal responsibility is involved" in every result into which this uniform operation works out. But Chambers, so far from denying this, was especially anxious to insist upon it. What he equally insisted upon, however, was the uniformity of this agency. When he spoke of the Creator as working "through" law, the expression, doubtless, was infelicitous; but his essential idea was plain and unexceptionable, viz., that neither organic nor inorganic phenomena "result from capricious exertions of creative power; but that they have taken place in a definite order, the statement of which order is what men of science term a natural law." These last words are Huxley's own, uttered in 1862, in an address before the Geological Society. It is, he added, logically possible to regard such a law as "simply the statement of the manner in which a supernatural power has thought fit to act"; the main thing is that "the existence of the law and the possibility of its discovery by the human intellect" be recognized. This was exactly the essence of the view for which Chambers was contending. Huxley was so unduly enraged by a bit of unscientific looseness of language that he actually overlooked the important idea which that language was manifestly intended to express.

[7] I have not had access to this article, published in the *Medical and Chirurgical Review;* but its character is sufficiently indicated in the correspondence of Huxley and Darwin. The former speaks of it as "the only review I ever have qualms of conscience about, on the ground of needless savagery." Darwin thought it "rather hard on the poor author"; and added a curiously mild intimation of his own belief: "I am perhaps no fair judge; for I am almost as unorthodox about species as the 'Vestiges' itself, though I hope not quite so unphilosophical" ("More Letters of Charles Darwin," I., 75).

capable of errors upon particular points which were palpable to every competent specialist.

Yet the layman was, after all, sound in his main thesis; and, what is far more significant, his thesis was based upon sound and sensible arguments, substantially the same arguments that Huxley was destined before long to use in the same cause, though with far superior skill as a debater. It will, I think, appear impossible to acquit the young Huxley of a certain measure of scientific Pharisaism in this episode. He was so shocked by minor breaches of scientific propriety, in the "Vestiges," that he forgot the weightier matters of the law of scientific method. In his irritation at Chambers's incidental slips in zoology, he became blind to the importance and suggestiveness of the general outline of that writer's reasoning. Quite other was Alfred Russel Wallace's reaction upon the little book. As early as 1845 he wrote:

I have rather a more favorable opinion of the "Vestiges" than you appear to have. I do not consider it a hasty generalization, but rather as an ingenious hypothesis, strongly supported by some striking facts and analogies, but which remains to be proved by more facts and the additional light which more research may throw upon the problem. It furnishes a subject for every observer of nature to attend to; every fact he observes will make either for or against it.[8]

By 1847 Wallace had become thoroughly convinced of the truth of transformism; and from that time forward his mind was occupied with the problem of explaining the cause and *modus operandi* of evolution. At this time, he writes:

The great problem of the origin of species was already distinctly formulated in my mind. . . . I believed the conception of evolution through natural law, so clearly formulated in the "Vestiges," to be, so far as it went, a true one; and I firmly believed a full and careful study of the facts of nature would ultimately lead to the solution of the mystery.

Wallace thus escaped the fatal error in logical procedure into which Huxley fell. For Huxley, in the passage already cited, gives as one of his two reasons for refusing to accept, even provisionally, the evolutionary hypothesis, the fact that "no adequate suggestion respecting the causes of the transmutation assumed" had then been made. But, that no causal explanation of a fact is at hand, is not good reason for denying the fact, if serious evidence of its reality is presented. Wallace properly discriminated the two issues; becoming first convinced that there was an established balance of scientific probability in favor of the fact, he then set himself upon the quest of a hypothesis that would explain it. He verily had his reward; a decade later he appeared, with Darwin, as joint author of the doctrine of natural selection.

[8] Wallace, "My Life," I., 254. Writing sixty years after, Dr. Wallace adds his final judgment of the "Vestiges," "a book which, in my opinion, has always been undervalued, and which, when it first appeared, was almost as much abused, and for much the same reasons, as was Darwin's 'Origin of Species' fifteen years later" (*ibid.*).

It is time to proceed to the proof of the contentions of this paper. In presenting it, I shall first recall to the reader passages—some of them, doubtless, already familiar—from Huxley or other post-Darwinian defenders of the evolution theory, and then exhibit the parallel arguments found in Chambers, Spencer and other pre-Darwinians. Since, in such a case, textual precision is of some importance, it is hardly needful to apologize for copious citation of the *ipsissima verba* of the authors in question. The arguments for evolution will be taken up in the order of their generality or of their logical interconnection.

It is necessary first of all, however, to remind the reader of the general outlines of the situation in the science of the time. It was a situation essentially different from that in which Lamarck had carried on the propaganda of transformism. The difference was due to two changes that had taken place in the intervening period. First, the science of geology had gone through a brilliant development, and had fought and won its battle against religious orthodoxy; and in England, though not all geologists were consistent uniformitarians, all geology had been profoundly influenced by the principles and the methods of Hutton and Lyell. Second, the two allied subsidiary sciences of paleontology and stratigraphic geology had been created, through the work of Cuvier and of William Smith. One result was that the recognized age of the planet had been vastly extended; enough time was thus granted for the evolutionary process. A still more significant result was that the Mosaic cosmogony had been entirely abandoned by even the most orthodox of men of science. The doctrine of creation which such men defended against the hypothesis of development no longer bore any close resemblance to the narratives of Genesis; it was no longer a question of a single, original creation of all things, but of a large number of repeated acts of "special creation," separated from one another by wide intervals of time, and confined to the production of organisms. Meanwhile, it was assumed, in the organic realm things were going on in an orderly and normal manner, in accordance with natural laws of geologic change; even the Cuvierian "catastrophes" were "natural" phenomena. The effect, in short, of the triumph of geology had been, curiously enough, to *increase* the resort to supernatural agency in the current accounts of the genesis of the existing order of nature. In place of one great, obscure miracle at the origination of the universe, the revised version of the doctrine of creation assumed a large number of petty and definite miracles; it supposed, in Chambers's words, "an immediate exertion of the creative power, at one time to produce zoophytes, at another time to add a few marine mollusks, another to bring in one or two crustacea, again to produce crustaceous fishes, again perfect fishes, and so on to the end."[9] Creationism, to conform to the accepted principles and accumulated knowledge of geological science, had been

[9] Chambers, "Vestiges," 1844, Ch. XI.

compelled, like the Ptolemaic astronomy before it, to interpolate some very singular epicycles in its hypothesis. And while all these miraculous interpositions were taking place in order to keep the organic kingdom in a going condition, the Creator was not for a moment allowed by the orthodox geologists to interfere in a similar manner in their own particular domain of the inorganic processes. Their attitude was like that of the French authorities who, a century earlier, suppressed the "miraculous cures" of the Jansenist abbé at the church of St. Médard in Paris, and, in a famous lampoon, were represented as posting the following proclamation on the church doors:

> De par le roi, défense à Dieu
> De faire miracle en ce lieu.[10]

So, in the ruling science of 1830–60, the only officially licensed place (outside of Palestine) in which miracles might be performed by the Creator was the domain of organic phenomena. Here, as a measure of compensation, the number of miracles scientifically sanctioned had been materially increased.[11]

It was a further consequence of these changes in the scientific situation that the men who, in the name of orthodoxy but under the mantle of science, attacked the pioneers of evolutionism, themselves taught doctrines no less completely at variance with the usual—and with any natural—interpretation of Scripture. Accommodations and forced interpretations had, indeed, been devised in abundance, to "harmonize" the new science with theology; but if these could be invented to justify geology, others could as well be, as they since have been, invented to justify evolutionary biology. Any consistent scriptural believer could make out as good a case of heresy against Cuvier, Owen, Sedgwick, Agassiz, or Hugh Miller, as against the author of the "Vestiges" or Herbert Spencer. These writers, therefore, occupied a position of a strange and rather damaging incongruity, as Chambers did not fail to point out:

> Strange to say, those who every day give views of physical cosmogony altogether discrepant in appearance with that of Moses, apply hard names to my book for suggesting an organic cosmogony in the same way liable to inconsiderate odium. . . . The views which I gave of this history of organization stand exactly upon the same ground upon which the geological doctrines stood, fifty years ago. . . . If the men newly emerged from the odium which was thrown upon Newton's theory of the planetary motions, had rushed forward to turn that odium upon the patrons of the dawning science of geology, they would have been prefiguring the conduct of several of my critics, hardly escaped from

[10] "By the king's order, God is hereby forbidden to perform miracles in this place."

[11] The reader will find amusing examples of this inconsistency in President Hitchcock's "The Religion of Geology," 1852, pp. 164–165, 339–340. Cf. also Gray and Adams, "Elements of Geology," 1854, pp. 16 and 89.

the rude hands of the narrow-minded, yet eager to join the rabble against a new and equally unfriended stranger, as if that were the best way of purchasing immunity for themselves. The public must soon see that if a literal interpretation of scripture is an insufficient argument against the true geognostic history of our earth, so also must it be against all associated phenomena, supposing they are presented on good evidence.[12]

In view of this situation, the arguments for evolution, in 1844 or 1859, were primarily significant, not as direct evidences in favor of one hypothesis, but as touchstones for deciding between the claims of two—the only two—rival hypotheses: that of the ready-made production of species, with their known characteristics and relations, by repeated special acts of creation; and that of their production through the gradual modification, in the course of natural descent, of earlier and simpler forms. Huxley, it is true, refused to face the alternative, and cried, "a plague o' both your houses!" Nothing can be said, however, in justification of such a position on the part of a man of science. *Hypotheses non fingo* has never been a sound or serviceable maxim; it had certainly not been by following it that the sciences of astronomy and geology had developed.[13] Now, if other hypotheses, beyond the two in question, were conceivable in 1844, certainly no others were seriously advanced. The first concern of a biologist of the period should, then, have been to compare the two hypotheses of the origin of species, in the light of the then known principles and facts, hereafter to be enumerated. This comparison, if made honestly, by a logically competent mind, must necessarily have led, at almost any time after 1840, to the conclusion to which Spencer tells us that he found himself forced somewhere about 1850. By this time, he says:

> The belief in organic evolution had taken deep root [in my mind] and drawn to itself a large amount of evidence—evidence not derived from numerous special instances, but derived from the general aspects of organic nature and from the necessity of accepting the hypothesis of evolution when the hypothesis of special creation had been rejected. The special creation belief had dropped out of my mind many years before, and I could not remain in a suspended state; acceptance of the only possible alternative was imperative.[14]

After these preliminaries, the reader is prepared for viewing the arguments for evolutionism, now to be recalled in a more detailed manner, in their proper historical and logical perspective.

1. *Argument from the General Presumption of Science against "Supernatural" Explanations of Phenomena.*—In his "Belfast Address," 1874, Tyndall pointed out that the main argument for evolu-

[12] Chambers, "Explanations," 1846, p. 120.

[13] Huxley later expressed this general truth forcibly enough; *e. g.*, "The Progress of Science," 1887. "Physical science rests on verified or uncontradicted hypotheses; and, such being the case, it is not surprising that a great condition of its progress has been the invention of verifiable hypotheses" ("Method and Results," 1902, pp. 61–62).

[14] Duncan, "Life and Letters of Herbert Spencer," 1908, II., 317.

tion lay in the superior congruency of the hypothesis—as contrasted with the special creation doctrine—with the methodological presuppositions of modern science and with the general view of nature which in most of the other provinces of science had already been accepted.

> The basis of the doctrine of evolution consists, not in an experimental demonstration—for the subject is hardly accessible to this mode of proof—but in its general harmony with scientific thought. From contrast, moreover, it derives enormous relative strength. On the one side we have a theory which converts the Power whose garment is seen in the visible universe into an artificer, fashioned after the human model, and acting by broken effects, as man is seen to act. On the other side, we have the conception that all we see around us and feel within us—the phenomena of physical nature as well as those of the human mind—have their unsearchable roots in a cosmical life, . . . an infinitesimal span of which is offered to the investigation of man. Among thinking people, in my opinion, this last conception has a higher ethical value than that of a personal artificer.

Reviewing the past triumphs of the scientific method over supernaturalism, he concludes:

> We claim, and we shall wrest, from theology the entire domain of cosmological theory. All schemes and systems which thus infringe upon the domain of science must, in so far as they do this, submit to its control. . . . Acting otherwise proved always disastrous in the past, and it is simply fatuous to-day.

Similarly Romanes put in the fore-front of the arguments for evolution

> The fact that it is in full accordance with what is known as the principle of continuity—by which is meant the uniformity of nature, in virtue of which the many and varied processes going on in nature are due to the same kind of method, *i. e.*, the method of natural causation. . . . The explanations of . . . phenomena which are at first given are nearly always of the supernatural kind. . . . Now, in our own day there are very few of these strongholds of the miraculous left. . . . No one ever thinks of resorting to supernaturalism, except in the comparatively few cases where science has not yet been able to explore the most obscure regions of causation. . . . We are now in possession of so many of these historical analogies, that all minds with any instincts of science in their composition have grown to distrust on merely antecedent grounds, any explanation which embodies a miraculous element. . . . Now, it must be obvious to any mind which has adopted this attitude of thought, that the scientific theory of natural descent is recommended by an overwhelming weight of antecedent presumption.

This "overwhelming weight of antecedent presumption" against special creation, and in favor of evolution, was pointed out by Chambers with entire clearness; his arguments present in part an almost verbal parallel to the passages I have quoted from Tyndall and Romanes. In the already established results of geology and astronomy, he writes in the "Vestiges":

> We have seen powerful evidence that the construction of the globe and its associates was the result, not of any immediate or personal exertion on the part of the Deity, but of natural laws which are expressions of his Will. What is to hinder our supposing that the organic creation is also the result of natural

laws, which are in like manner the expression of his Will? . . . The fact of the cosmical arrangements being an effect of natural law, is a powerful argument for the organic arrangements being so likewise; for how can we suppose that the august Being who brought all these countless worlds into form by the simple establishment of a natural principle flowing from his mind, was to interfere personally whenever a new shell-fish or reptile was to be introduced in one of these worlds? Surely this idea is too ridiculous to be for a moment entertained. This would certainly be to take a very mean view of the Creative Power—in short to anthropomorphize it.

In his "Explanations,"[15] 1846, he puts the considerations urged by Romanes far more tellingly than Romanes put them forty years later. Chambers wrote:

The whole question stands thus: For the theory of universal order—that is, order as presiding both in the origin and administration of the world—we have the testimony of a vast number of facts in nature, and this one in addition—that whatever is reft from the domain of ignorance and made undoubted matter of science, forms a new support to the same doctrine. The opposite view, once predominant, has been shrinking for ages into lesser space, and now maintains a footing only in a few departments of nature which happen to be less liable than others to a clear investigation. The chief of these, if not the only one, is the origin of the organic kingdoms. So long as that remains obscure the supernatural will have a certain hold upon enlightened persons. . . . One after another the phenomena of nature, like so many revolted principalities, have fallen under the dominion of order and law; but here is one little province still faithful to the Bœotian government; and as it is nearly the last, no wonder it is so vigorously defended. As in the political world, however, men do not trust in the endurance of a dynasty which is reduced to a single city or nook of its dominions, so we may expect a speedy extinction to a doctrine which has been driven from every portion of nature but one or two limited fields.

Huxley, it is true, seems in his pre-Darwinian period to have disapproved of this type of argument; creation being "perfectly conceivable . . . the so-called *a priori* arguments against the possibility of creative acts" appeared to him "to be devoid of reasonable foundation." This, of course, was a perverse misapprehension of the issue. It was not a question of conceivability, but of the relative probability of the only two available hypotheses. And the first criterion of probability in such a case must be the agreeement of any proposed hypothesis with the general type of hypothetical explanations which the whole previous experience of men of science has found to be capable of fruitful application, and of the sort of verification which comes through fruitful application. By such a criterion, no hesitation between the two hypotheses was admissible. "Special acts of creative volition" had never been found by science to be a *vera causa* at all; the hypothesis was vague, sterile, impossible of verification, contrary to all the principles of method by the use of which the past successes of science had been achieved; "gradual development through natural descent" was, as a

[15] This supplement to the "Vestiges" seems to be little known; it is in many respects superior to the original volume.

working theory, definite, suggestive of precisely formulable problems to which inductive tests could be applied, harmonious with the initial assumptions through which several other disciplines had already been converted from mere masses of information into sciences. Huxley later saw this clearly enough, and expressed it forcibly, though he never seems to have confessed the unreasonableness of his earlier position. The publication of Lyell's "Principles of Geology" in 1830, wrote Huxley[16] in 1887, "constituted an epoch in the modern history of the doctrine of evolution, by raising in the mind of every intelligent reader this question: If natural causation is competent to account for the not-living part of our globe, why should it not also account for the living part?" If every intelligent reader had this question in his mind after 1830, it is a little singular that Huxley himself, and almost every other naturalist of the period, saw no importance whatever in the reasonings of Chambers, Spencer, Baden Powell, and a few others, who were the only *writers* of the time to press the question home.

2. *The Argument from Uniformitarianism in Geology.*—Huxley, indeed, from the time of his conversion to Darwin's views, always set great store by the argument from the presumptions of scientific method; but usually in a more specialized and less philosophical form of it. Geology was, in England, the dominant and the most brilliantly successful science of the first half of the century; and Lyell had made it a working principle of geological reasoning that past phenomena, not directly open to experiment, were, so far as possible, always to be referred to the operation of "causes" similar to those now at work. Whether the uniformitarian doctrine was not, as some contemporary geologists hold, a good deal overstrained by Lyell, it does not lie within the purpose of this paper to ask; at all events, the doctrine was accepted by Huxley and most of the men of science of that time. And in uniformitarianism evolutionism seemed to Huxley—after 1858—to be directly implied. We find him writing Lyell in June, 1859:

> I by no means believe that the transmutation hypothesis is proven, or anything like it. But I view it as a powerful instrument of research. Follow it out, and it will lead us somewhere; while the other notion is, like all the other modifications of "final causation," a barren virgin. . . . I would very strongly urge upon you that it is the logical development of uniformitarianism.

In the self-same paper in which we saw Huxley justifying his refusal for some twelve years to adopt the doctrine of transformation, even as a working hypothesis, there is also to be found the following passage:

> I have recently read afresh the first edition of the "Principles of Geology"; and when I consider that for nearly thirty years this remarkable book had been in everybody's hands, and that it brings home to every reader of ordinary intelligence a great principle and a great fact—the principle that the past must be

[16] "Method and Results," "The Progress of Science," p. 99.

explained by the present unless good cause can be shown to the contrary; and the fact that, so far as our knowledge of the past history of life on our globe goes, no such cause can be shown—I can not but believe that Lyell was, for others, as for myself, the chief agent in smoothing the road for Darwin. For consistent uniformitarianism postulates evolution as much in the organic as the inorganic world. The origin of a new species by other than ordinary agencies would be a vastly greater "catastrophe" than any of those which Lyell successfully eliminated from sober geological speculation.[17]

But however much Lyell may have "smoothed the road," Huxley, and most of the biologists of those thirty years, declined to go in thereat. It remained for an anonymous amateur, whom they thereupon with one accord fell to abusing, to point out the practicability of that highway. In the "Vestiges" and the "Explanations" Chambers urged the presumption from geological uniformitarianism with an effective use of concrete examples.[18]

If there is anything more than another impressed on our minds by the course of geological history, it is that the same laws and conditions of nature now apparent to us have existed throughout the whole time. Admitting that we do not now see any such fact as the production of new species, we at least know that, while such facts were occurring upon earth, there were associated phenomena of a perfectly ordinary character. For example, when the earth received its first fishes, sandstone and limestone were forming in the manner exemplified a few years ago in the ingenious experiments of Sir James Hall. . . . It was about the time of the first mammals that the forest of the Dirt Bed was sinking in natural ruin amidst the sea sludges, as the forests of the Plantagenets have been doing for several centuries upon the coast of England. In short, *all the common operations* of the physical world were going on in their usual simplicity, obeying the laws which we now see governing them; while the supposed extraordinary causes were in requisition for the development of the animal and vegetable kingdoms. There surely hence arises a strong presumption against any such causes.

It is a curious circumstance, however, that the argument from uniformitarianism cut both ways. As Wallace says:

One of the greatest, or perhaps we may say the greatest, of all the difficulties in the way of accepting the theory of natural selection as a complete explanation of the origin of species, has been the remarkable difference between varieties and species with respect to fertility when crossed.[19]

This difference, as Darwin said in the "Origin," seemed, on the face of it, "to make a broad and clear distinction between varieties and species." And the apparent existence of such a radical distinction between the varieties produced under domestication and true physiological species was an objection, not only against natural selection, but also against evolution itself; for it meant that we do *not* see now, nor within the limits of human observation, organisms actually getting

[17] "Life and Letters of Charles Darwin," Ch. XIV. The letter to Lyell is in "Life and Letters of Thomas Henry Huxley," I., 174.

[18] "Vestiges," reprint in "Morley's Universal Library," 1890, p. 114.

[19] "Darwinism," p. 152.

transformed, through the accumulation of variations, into new species differing from their progenitors by the final test of specificity of character. In the 1850's such a radical distinction seemed to hold; even by the sixth edition of the "Origin," dated 1872, Darwin was able to point to only four somewhat debatable instances, in plants, of the infertility of varieties when intercrossed. If this difficulty appeared to Huxley and other zoologists an insuperable objection to evolutionism before 1858, it was not, in Huxley's opinion, removed after that date. Yet he no longer found the difficulty insuperable; it was purely a negative argument, *e silentio,* and he had faith to believe that by further investigation it would be removed. In his Edinburgh lectures of 1862, "he warned his audience of the one missing link in the chain of evidence—the fact that selective breeding has not yet produced species sterile to one another. But it is to be accepted as a working hypothesis, like other scientific generalizations, 'subject to the production of proof that physiological species may be produced by selective breeding.'" In the same year Huxley wrote Darwin:

> I have told my students that I entertain no doubt whatever that twenty years' experiments on pigeons, conducted by a skilled physiologist, instead of by a mere breeder, would give us physiological species sterile *inter se* from a common stock, . . . and I have told them that when these experiments have been performed I shall consider your views to have a complete physical basis.[20]

It is certainly interesting thus to observe that, as Huxley, before his conversion, saw no potency in arguments which afterwards seemed to him conclusive, so also he was able, in his second phase, to pass over by an act of faith one of the most serious of the pre-Darwinian objections to evolutionism. This provisional disregard of the "missing link" in an argument otherwise impressively well concatenated was, under the circumstances, far from unreasonable. But it would have been equally reasonable in 1846 or in 1851.

Leaving these antecedent considerations in favor of evolutionism drawn from the general principles of scientific method, I turn to the more specific facts which—when illumined by those principles—provide the now usual and familiar arguments for the theory. All the more essential of these facts were known before 1844; and attention was duly called to their bearings by the neglected prophets of evolutionism during the fifteen years preceding the publication of the "Origin of Species." In speaking of these "facts," it is well to explain what is meant, in this connection, by the expression. The theory of evolution does not rest immediately upon an induction of individual phenomena; and the evidence for it did not increase by a slow arithmetical progression, through the accumulation of observations of individual phenomena. It is a generalization established inferentially, by

[20] Huxley's "Life and Letters," I., 193, 195.

virtue of the fact that it unifies and explains a number of lesser generalizations, themselves for the most part established by direct induction, in several special sciences. When, in these separate sciences, the subsidiary generalizations underlying the theory of the transformation of species were well established, and generally accepted by specialists, the evidence for evolution must be said to have been logically complete. This does not mean that more facts were not subsequently added; it does mean that the argument was adequate without them, and that no one who found the original evidence unconvincing had any logical ground for being convinced by any of the considerations adduced in the "Origin of Species" or in Huxley's earlier evolutionary writings.

3. *Argument from the Homologies in Vertebrates.*—This argument was, by 1844, already so old and even hackneyed a one, that it may, in a consideration of the status of the evolutionary argument at that special period, be passed over very briefly. The facts upon which the argument rests had been in the possession of zoologists ever since Buffon and Daubenton had laid the foundations of the science of comparative anatomy (1749). These facts chiefly had, before the end of the eighteenth century, made evolutionists of Diderot,[21] of Kant, and (but for perfunctory reservations in favor of religious orthodoxy) of Buffon himself. It can, therefore, scarcely be necessary to cite evidence to show that the argument was familiar a quarter of a century after the whole conception of homologous organs had been clearly elaborated by E. Geoffroy St. Hilaire.[22] Nor, for the purposes of the present paper, is it necessary to estimate the precise logical weight of this argument when it stands alone. At the time with which this inquiry is concerned, it did not stand alone, but had been complemented by a number of considerations more recently brought to light by scientific discovery.

4. *Argument from the Variability of Existing Species.*—Not less old than the last-mentioned was the argument from the fact that existing—and, especially, domesticated—species have a marked tendency to variation, exhibit an extensive diversity of form, and are capable of transmitting variations to their descendants. It was mainly this group of facts that had caused Maupertuis[23] to embrace the evolutionary hypothesis before 1751. The same argument, with that from the homologies, is set down by Erasmus Darwin in the "Zoonomia," 1794, as among the principal reasons for believing in the transformation of species. We are led to such a belief, wrote the grandfather of the author of the "Origin,"

> When we think of the great changes introduced into various animals by artificial or accidental cultivation, as in horses, . . . or in dogs, . . . or in the

[21] *Cf.* Lovejoy, "Some Eighteenth Century Evolutionists," THE POPULAR SCIENCE MONTHLY, August, 1904, pp. 323–327.

[22] In his "Philosophie Anatomique," 1818.

[23] *Cf.* Lovejoy in THE POPULAR SCIENCE MONTHLY, July, 1904.

changes of form in cattle. Add to these the differences we daily see produced in smaller animals by our domestication of them, as rabbits or pidgeons, or from the differences of climate or even of seasons. . . . Add to these the various changes produced in the forms of mankind by their early modes of exertion, or the diseases occasioned by their habits of life, both of which become hereditary, and that through many generations.[24]

The argument had often been repeated in the nineteenth century; and in the period under consideration we find Spencer observing that

> The supporters of the Development Hypothesis . . . can show that the degrees of difference so produced [through structural changes under altered conditions] are often, as in dogs, greater than those on which distinctions of species are in other cases founded. They can show that it is a matter of dispute whether some of these modified forms *are* varieties or separate species.[25]

This argument, it is true, if taken by itself, suffered from two serious limitations. One has already been adverted to, in another connection: the absence of evidence that variation can produce varieties sterile *inter se,* as species are sterile. But we have already seen that this difficulty, upon the testimony of Huxley himself, was not removed in 1859. The other limitation of the argument was that, before the promulgation of the hypothesis of natural selection, it was commonly associated with a belief in the inheritance of acquired characters. But this association was not logically necessary; and in any case, the wholesale denial of such inheritance is a doctrine of neo-Darwinism unknown to the pre-Darwinian period and to Darwin himself; and was in that period, therefore, not a ground of difficulty.

In a subsequent instalment of this inquiry it will remain to consider, somewhat more minutely, four more of the principal general arguments for evolutionism, three of these being, in 1844, of a much less venerable age than the two last mentioned.

(To be concluded)

[24] "Zoonomia," 1794, pp. 500–501. The elder Darwin, it will be noted, believed in the inheritance of acquired characters; he might be called an eo-Lamarckian.

[25] "The Development Hypothesis," 1852.

THE PROGRESS OF SCIENCE

LORD KELVIN

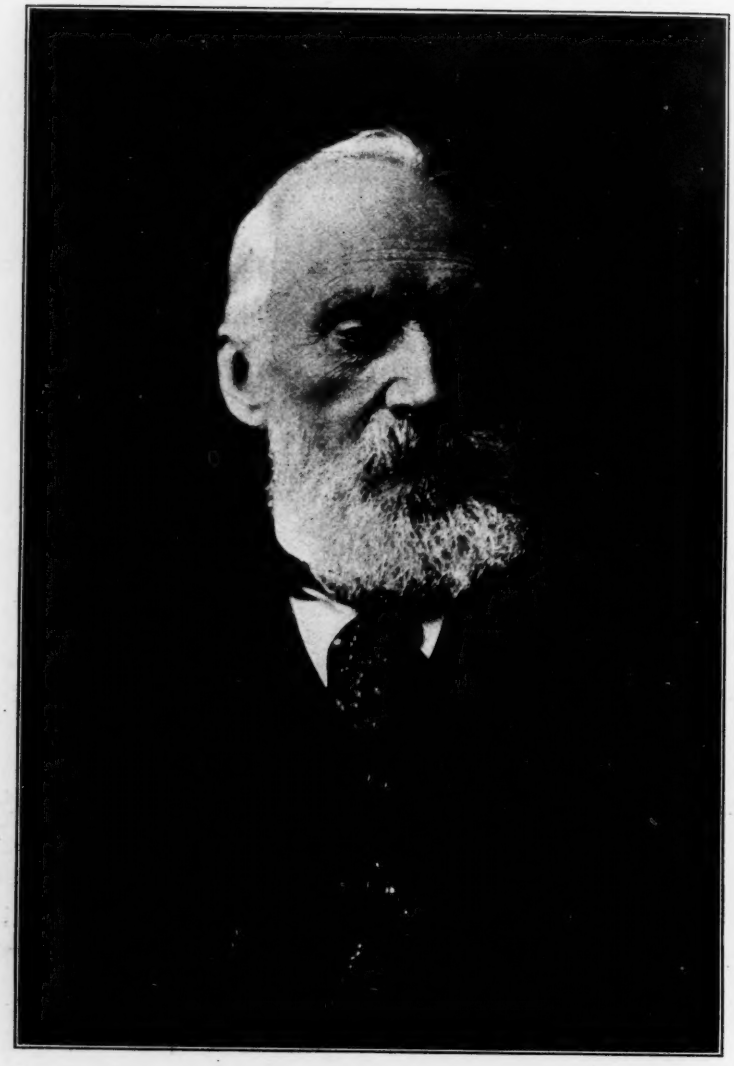
THE two great advances of modern science, perhaps the two most notable human achievements, are the doctrine of organic evolution and the doctrine of the conservation of energy. All the world has this year been celebrating the hundredth anniversary of Darwin's birth. William Thomson, born fifteen years later, occupies in the physical sciences a position almost equal to that of Darwin in the biological sciences. It is a striking fact that Great Britain should have produced these two great men in the same rank with Newton, by whom, and near Darwin, Kelvin nearly two years ago was buried in Westminster Abbey.

Thomson, like Darwin, appears to have been impressed with hereditary genius; his father was professor of mathematics and his brother professor of engineering. Unlike Darwin, typifying a distinction which seems to obtain between the mathematical sciences and the sciences of observation, Thomson was precocious. He matriculated at Glasgow University at the age of ten and attended his father's classes in mathematics. He published a mathematical paper of consequence before going to Cambridge as a student at the age of seventeen, and during his years as an undergraduate at Peterhouse, he published a number of papers on mathematical physics, which fully represented the direction and characteristics of the work which was continued for more than sixty years. He became professor of natural philosophy at the University of Glasgow at the age of twenty-two. At Cambridge Thomson rowed on his college boat and won the Calquhoun sculls, one of the chief athletic competitions of the university. He was one of the founders of the musical society of the university and played at its concerts.

This vigorous versatility was maintained to the end of his long life. The laying of the Atlantic cable, the fixing of units on which electrical engineering is largely based, the invention of electrical and other instruments, many of which were patented and produced a large fortune, seem almost incompatible with his theoretical work in mathematical physics, though it is true that his mathematical analyses were kept in close touch with actual facts. It seems odd to an American that he should have changed the name that had become familiar and famous, if indeed the peerage itself is worth while when there are no heirs to whom it can be bequeathed. Darwin, to whom no peerage was offered but who bequeathed his name and a large measure of his scientific genius to his sons, seems in this respect to have enjoyed the better fortune. Kelvin visited this country three times and is associated with it both by his work on the Atlantic cable and by the fact that some of his most important theoretical deductions were made known in the form of lectures at the Johns Hopkins University.

An admirable account of Kelvin's scientific work has been contributed to the *Proceedings* of the Royal Society by Sir Joseph Larmor. From this monograph we reproduce three portraits—the two earlier ones on a reduced scale. It would be fortunate if it were possible to reproduce the lucid exposition of the development of Kelvin's contributions to science and their relations to the work of his predecessors and contemporaries.

In 1848 it was possible for Thomson to maintain the view that heat is a substance which may produce energy



Yours very truly
Kelvin

WILLIAM THOMSON
in 1854.

in falling to a lower temperature or may diffuse passively. But in 1844 Joule had made known his experiments establishing the transformation of heat into work, and in 1847 Helmholtz had published his classical memoir on the conservation of energy. Mayer's earlier paper was first brought to general notice by Joule in 1849. Maxwell published his first paper in 1856, but did not reach the electric theory of light until eight years later. Clausius presented his paper on the motive power of heat to the Berlin Academy in 1850. It was indeed a marvelous period in the history of physics. Among the giants of those days, Thomson stands almost or quite preeminent. His great paper on the dynamical theory of heat was published in 1851, and laid firmly the foundations of the scientific treatment of energy.

In 1849 Thomson published his memoir on the mathematical theory of magnetism, on which subject he had already written four years earlier. This was followed by his remarkable contributions to the theory of electricity and light. In later years his attention was directed to the structure of the ether and of matter. His limitation of the age of the earth gave much concern to geologists and biologists, which the more recent advances of physics has again relieved, though the episode was probably of advantage to the natural sciences.

Even in the briefest note, reference should be made to Thomson and Tait's "Treatise on Natural Philosophy," an epoch-making text, which Helmholtz translated into German, and to the admirable popular lectures which fill three volumes. The contributions to electrical engineering have already been mentioned. Thomson was the leader in the advances by which steam is being supplanted by electricity.

An adequate appreciation of Kelvin's personality is quoted by Sir Joseph Larmor from the address of Lord Roseberry when installed as Kelvin's successor in the chancellorship of the University of Glasgow: "In my personal intercourse with Lord Kelvin, what struck me was his tenacity, his laboriousness, his indefatigable humility. In him was visible none of the superciliousness or scorn which sometimes embarrass the strongest intellects. Without condescension, he placed himself at once on a level with his

WILLIAM THOMSON
in 1877.

companion. That has seemed to me a characteristic of such great men of science as I have chanced to meet. They are always face to face with the transcendent mysteries of nature. . . . Such labours produce a sublime calm, and it was that which seemed always to pervade Lord Kelvin. Surely in an age fertile in distinction, but not lavish of greatness, he was truly great."

A PHOTOGRAPH OF HALLEY'S COMET

EDMUND HALLEY, born in 1656, Savilian professor of geometry at Oxford and later Flamsteed's successor as astronomer royal, made notable contributions to astronomy and cosmical physics. He was the first to catalogue the stars of the southern sky; he studied the orbits of Jupiter and Saturn; he detected the acceleration of the moon's mean motion; he used the transit of Venus to determine the solar parallax; he discovered the proper motion of the fixed stars; he suggested the magnetic origin of the aurora borealis; he studied terrestrial magnetism and located magnetic poles; he surveyed the tides and coasts of the British Channel; he cooperated with Newton in the publication of the "Principia."

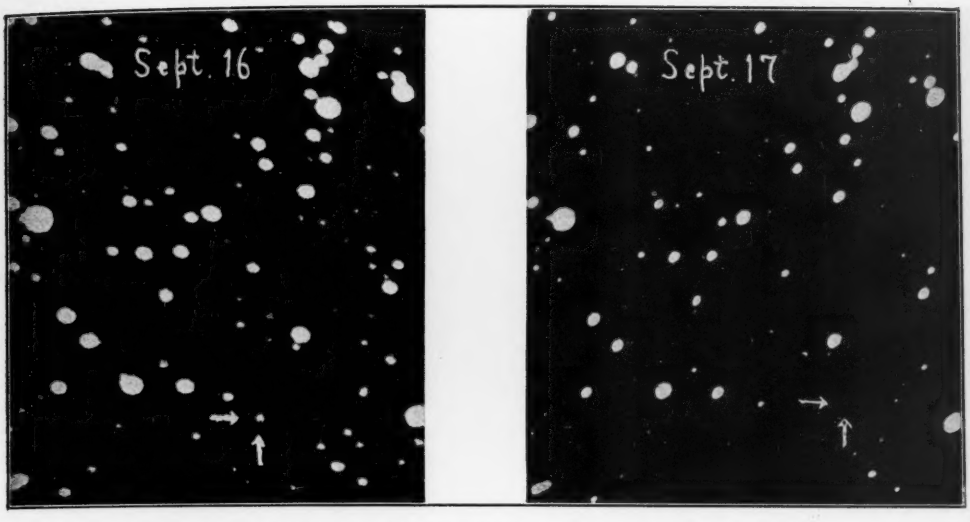
But outside the circle of astronomers, Halley's name is known because it is attached to a comet whose orbit he calculated and whose return he predicted. This was in 1682, when Halley computed its parabolic orbit, and comparing this with the imperfect observations of comets which had appeared in 1456, 1531 and 1607, concluded that each was the same body returning from the outer region of the solar system beyond the furthest known planet. He wrote: "Wherefore, if it should return according to our predictions about the year 1758, impartial posterity will not refuse to acknowledge that this was first discovered by an Englishman."

This was not only a great advance in astronomy and important in its relation to the theory of gravitation, but was a forward movement in the conception of the orderliness of the universe. Comets had been portents of war, pestilence and famine. It was indeed Halley's comet which appeared in 1066 at the time of the invasion of William the Conqueror and again in 1456 when Constantinople was besieged by the Turks and the crescent-shaped tail was a mighty omen.

Halley's comet duly appeared in 1759, somewhat retarded by the attraction of Jupiter and Saturn, its perturbations having been accurately calculated by the French astronomer, Clairaut. It appeared again in 1835 and is now once more rapidly approaching the earth and the sun, having passed the orbit of Jupiter in April last. It has been observed by Professor Max Wolf, of Heidelberg, and we are able to give here photographs taken by Mr. Oliver J. Lee with a two-foot reflector at the Yerkes Observatory. These are printed by the courtesy of Dr. Edwin B. Frost, director of the observatory and editor of the *Astrophysical Journal*, where they are also printed.

The plate of September 16 was taken with an exposure of 180 minutes, standard central time of mid-exposure being $14^h\,45^m$ (2:45 A.M. Sept. 17). The comet's position, as measured on the plate, was R.A. $6^h\,18^m\,56^s$, Dec. $+\,17°\,9'\,23''$. The plate of September 17 was exposed for 130 minutes, mid-exposure at (central standard time) $14^h\,10^m$ (2:10 A.M. Sept. 18). The right ascension had increased by 4^s, and the declination had decreased by $23''$. The arrows indicate the position, and also the components of the direction of the comet's motion.

The original negatives are magnified about ten times, and the scale of the pictures here is about $8''.5$ to the millimeter, or 3.5 minutes of arc to the inch; in other words, the width of each picture is about one seventh of a degree. The new Lumière "Sigma" plates were used, a fresh and clean



IN THESE PHOTOGRAPHS HALLEY'S COMET IS INDICATED BY THE ARROWS.

emulsion having been provided by the manufacturers. The faintness of the comet on the plate of September 17 was due to the poor sky, and not to any change in the comet's brightness. The brightest star shown in the pictures, near the left-hand edge, slightly above the center, is of magnitude 8.7, or about ten times fainter than the limit of naked-eye visibility. Stars at least as faint as the seventeenth magnitude, or twenty-five thousand times fainter than naked-eye visibility, are shown on the original negatives, and the comet's brightness must have been considerably less than this, more accurate determinations being now in progress at the hands of Mr. Parkhurst.

The comet was first observed visually by Professor Burnham, with the forty-inch telescope, on September 15. It was also observed visually by Professor Barnard on September 17 and several subsequent nights. Professor Barnard's visual estimate of the comet's brightness at his last observation before the moonlight interfered, on the early morning of September 27, was that it was of magnitude 14 or 14.5. His measures indicated a diameter of about 10″, but the object was without definite boundary.

The comet will be visible to the naked eye early next year and will attain its greatest brightness in the month of May.

SCIENTIFIC ITEMS

WE record with regret the death of Dr. Washington Irving Stringham, professor of mathematics in the University of California; of Dr. Leonard Pearson, dean of the Veterinary School of the University of Pennsylvania, and of Professor Anton Dohrn, the eminent zoologist, founder and director of the Naples Zoological Station.

DR. A. LAWRENCE LOWELL was installed as president of Harvard University on October 6, and Dr. Ernest Fox Nichols was installed as president of Dartmouth College on October 14. The inaugural addresses, which are devoted to the condition of the American college, are printed in *Science* for October 15.

DR. EDMUND C. SANFORD, A.B. (California, '83), Ph.D. (Johns Hopkins, '88), professor of experimental psychology in Clark University, has been elected president of Clark College to succeed the late Carroll D. Wright.—Dr. J. F. Anderson has been appointed

director of the Hygienic Laboratory, Washington, D. C., to succeed Dr. M. J. Rosenau, who retires from the Public Health Service to accept a professorship of preventive medicine and hygiene at Harvard University.

DR. IRA REMSEN, president of the National Academy of Sciences, has consented, at the request of Dr. H. F. Osborn, president of the American Museum of Natural History, and Mr. Archer Huntington, president of the American Geographical Society, to appoint a scientific commission to examine the records of Lieutenant Peary and Dr. Cook, in case they are ready to present them to such a commission. Lieutenant Peary has accepted the suggestion.

PROFESSOR GEORG LUNGE, the eminent chemist of Zurich, was presented on September 19 with a gold medal bearing his portrait and the sum of 40,000 francs to celebrate his seventieth birthday and the jubilee of his doctorate. Chemists were present from many countries and addresses were delivered by a number of delegates. Professor Lunge in his reply announced his intention of giving the money to the Polytechnic Institute for the aid of students of chemistry.—On the occasion of the recent Leipzig celebration Dr. Wilhelm Wundt, the eminent psychologist, who made the principal address, was given the title of excellency. He was also made an honorary citizen of the city of Leipzig.

AT the meeting of the Chemists' Club, New York, held on October 8, it was announced that a Chemists' Building Company had been organized, for the purpose of acquiring a plot of ground and erecting thereon a large scientific building, the lower floors of which are to be rented to the Chemists' Club on a long lease, to contain scientific meeting rooms, a library and a museum, as well as the ordinary facilities required by a social organization, including sleeping apartments for its members. The upper floors of the building are to be leased for scientific offices and laboratories.

YALE UNIVERSITY has received from Mr. William D. Sloane and Mr. Henry T. Sloane the sum of $475,000 to build, equip and endow a physical laboratory. —The University of Pennsylvania proposes to erect during the coming year a building for its graduate school, costing $250,000.—The Pratt Institute of Brooklyn has received the sum of $1,750,000 from Mr. Charles M. Pratt, son of the founder and now its president, and from his five brothers and his sister, Mrs. E. B. Dane.